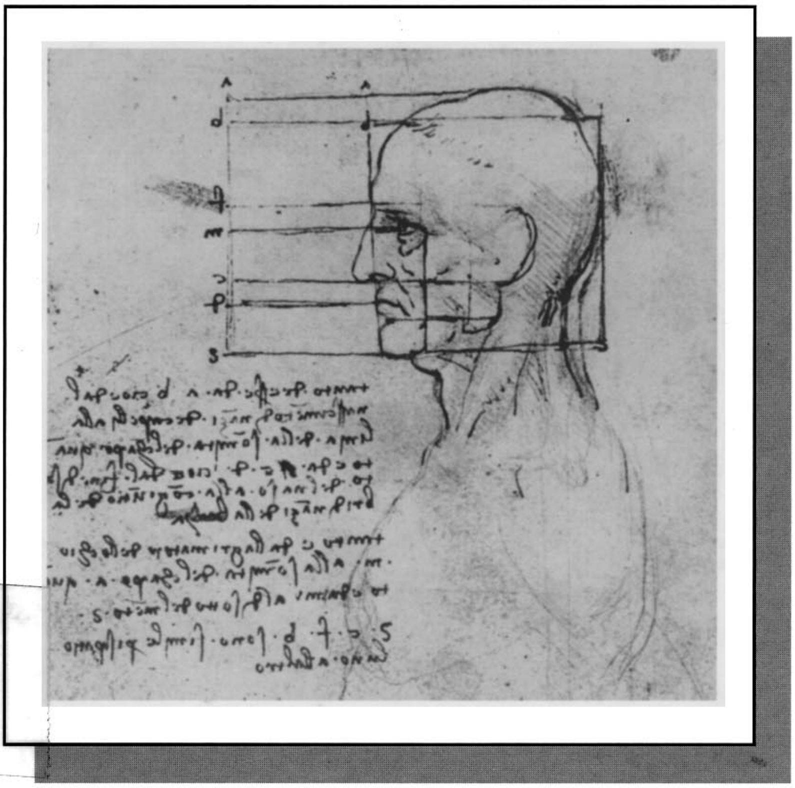
ORTHODONTICS

and

DENTOFACIAL ORTHOPAEDICS



A Comprehensive Textbook

Edited by
John P Fricker

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Preface

This publication is an effort to compile a comprehensive text. However, no single book can offer the student or practitioner a total package of orthodontic knowledge. The purpose of this book is to provide a scientific principles approach to clinical practice. It focuses on the critical elements of a conceptual understanding of orthodontics: biology, diagnosis, mechanics and materials. Particular care has been taken by all contributors to ensure the text reflects current principles and practice and is fully referenced.

This book describes a wide range of methodologies, systems and appliances. Too often orthodontics is presented simplistically as a *technical* skill of moving teeth for which 'cook book' methods offer tempting solutions. However, these are frequently inadequate. For practitioners requiring more evangelism about specific techniques there are many handbooks and short courses with step-by-step maps to the holy grail of the perfect bite.

Often in our preparedness to embrace new ideas, we risk overlooking past knowledge and experience and much can be lost. Invariably, there is a wide range of treatment options and no particular method or system should be perceived as necessarily better than another. We can learn something from them all. Most modern orthodontic techniques have the capacity to achieve the desired outcomes. The technique used is less consequential than how the operator drives the system. While critical analysis and discourse with regard to different methodologies are to be encouraged, comparative criticism can be superficial and stereotyped at best and at worst, misleading.

I recommend this book to all students and practitioners of orthodontics. Given the pace of research and technology the book will require future revision. I hope you find it a valuable and essential reference of theoretical and practical advice.

John P Fricker

Acknowledgements

I most sincerely congratulate and thank the contributors for their time, patience and perseverance throughout the preparation of this textbook. It has evolved as a collective effort of forward thinking academics and clinicians whose enthusiasm for orthodontic excellence has been my motivation.

In the beginning, compiling a new textbook seemed an ambitious undertaking. I was most heartened by the contributors faith and confidence in me to bring the book to publication.

Professor Wayne Sampson has always been a sympathetic and stimulating colleague and I acknowledge him for his positive encouragement and generous support.

I am also grateful to my practice staff for their assistance in the preparation of the manuscript and to Jacquii McLeay for the desktop publishing.

Finally, I dedicate this book to my family - my wonderful wife Kate and my two brilliant sons, Edward and Anthony.

John P Fricker

Foreword

The twentieth century has witnessed spectacular technological advances and we now live in a relentlessly information-hungry world community. As this century bustles toward the dawning of the new millennium, it is increasingly difficult to produce the definitive text on any topic, typical of which is the breathless pace of change in the field of cranio-facial biology at the molecular, morphological and clinical management levels. The present book is a timely compilation of contemporary orthodontic knowledge and has been developed from a uniquely Australasian perspective.

The first three chapters provide valuable analysis of dental arch development, aetiology of dento-facial disharmony and management of the adolescent orthodontic patient with an emphasis upon re-conceptualising the notion of patient compliance.

Chapter 4 provides extremely useful information on clinical photography updated to include digital image capture while Chapter 5 comprehensively discusses radiographic imaging equipment, techniques, safety and the new technologies of computed radiology; three dimensional imaging, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), radionuclide scanning and single photon emission computed tomography representing significant advances in recent years. Chapter 6 is a substantial contribution to the art and science of cephalometric analysis, encapsulating growth evaluation and visual treatment objective information into a student-friendly format.

From Chapter 7, which identifies mixed dentition treatment options, a distinct clinical emphasis prevails offering appropriate theory and strong practical suggestions to manage a broad spectrum of malocclusion types. Chapter 8 epitomises the thoughtful approach needed to diagnose and manage the maxillary impacted canine but the detail is such that it translate easily to the efficient management of most impacted teeth. Fixed appliance systems are considered in an interesting and updated revision of Begg mechanics (Chapter 9), a "how to do it" approach to lingual mechano-therapy (Chapter 10), the latest developments in the Tip-Edge appliance (Chapter 11) and the pre-adjusted appliance (Chapter 12) philosophies; all of which provide a wealth of information for novice and experienced practitioner alike.

Functional appliances have attracted much attention in the literature and many clinical pearls are offered in Chapter 13 with complimentary detail concentrating upon the design and use of the Clark Twin Block being offered in Chapter 14.

No orthodontic text could be complete without a consideration of the biological processes involved with orthodontic tooth movement and Chapter 15 succinctly provides a superb glimpse into the complex molecular interactions mediating the tissue remodelling necessary to achieve simple (?) tooth repositioning. This chapter exemplifies the rapidly evolving science which increasingly underpins our clinical procedures.

Returning to clinical applications, Chapter 16 offers valuable diagnostic and prediction planning information essential to the achievement of quality orthognathic surgical results. Many good ideas and sound advice are presented for the non-surgical treatment of Class II (Chapter 17) and Class III (Chapter 18) malocclusions with the pragmatic insight of clinicians with many years of practical experience.

The penultimate Chapter 19 addresses the sobering reality of post-treatment change and discusses various strategies to recognise and to guard against the many factors contributing to orthodontic relapse.

Consistent with the theme of keeping abreast of rapidly changing technology, Chapter 20 is an excellent update on materials used in orthodontics. Today's orthodontists have an exciting choice of brackets, wires and bonding agents, all of which are contributing to improved aesthetics and treatment outcomes for our patients. What will the future bring?

John Fricker and all contributors to this text have devoted much time, expertise, and effort to produce a highly readable and informative book from which all students of dento-facial variation can benefit. Such is the pact of modern knowledge acquisition that some aspects of the book may soon require revision but there is a strong core of good commonsense diagnostic principles which will serve as a valued reference well into the new millennium.

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1 Development of the Dentition and Normal Occlusion

Beverley Hookey

INTRODUCTION

An understanding of the development of the dentition and normal occlusion is crucial to successfully practising orthodontics. The clinical problem is to identify a burgeoning malocclusion from the developmental changes which occur in a physiologic state of occlusion. An awareness of what occlusal irregularities can be expected to self-correct and what developmental dentitional changes may exacerbate an existing malocclusion can also be obtained from an understanding of the development of the dentition and normal occlusion.

The development of the dentition is a continual process during growth, beginning *in utero*, and occurring on a timescale relatively independent of facial and skeletal growth. For convenience, the development of the dentition can be divided in to four stages: the deciduous dentition, the mixed dentition, the permanent dentition and the late permanent dentition with the eruption of the third molars. The changes in the occlusion expected to occur with growth and development will be described, beginning with the development of the dentition, summarising tooth formation, describing the eruptive process and describing and measuring the development of the dentition. This development begins with tooth formation and ossification of the maxilla and mandible prior to birth and can be said to continue well after the full permanent dentition has erupted.

DEVELOPMENT OF THE DENTITION

Tooth Formation

There are three main histologically described entities of tooth formation: the enamel organ or dental lamina which produces ameloblasts and enamel; the dental papilla, which produces the dentine, pulp and odontoblasts; and the dental sac, which produces cementum, fibroblasts to form the periodontal membrane and osteoblasts to form alveolar bone.

Tooth formation begins during the somite period at 21-31 days as ectomesenchyme of neural crest origin migrates to the oral region and interacts in a very specific manner with oral ectoderm. This in turn leads to the proliferation of the enamel organ, or a thickening shelf of oral ectoderm termed the dental lamina. The dental lamina grows down like an invaginated balloon into the

condensed mesenchyme, largely enveloping the latter. The deciduous tooth buds develop from the dental lamina and the permanent tooth buds develop lingual to the enamel organ of the deciduous tooth and extend posteriorly from the second deciduous molar from the fourth month of intra-uterine life. The tooth bud increases in size with the enamel organ appearing more and more like an upturned bowl filled by the developing mesenchymal tissues of the dental papilla. The alveolar bone gradually encloses the developing enamel organ; eventually the enamel organ loses any direct connection with the oral epithelium, although remnants of the dental lamina may persist as the gubernaculum dentis.

The dental sac or follicle is an organised connective tissue investment of the developing tooth, in direct contact with the enamel organ and separated from the surrounding alveolar bone by a loose vascular connective tissue.

The dental papilla consists of a network of mesenchymal cells connected by thin protoplasmic strands and separated by an amorphous ground substance. This tissue becomes increasingly vascular as development proceeds.

At a certain point in time, the cells of the enamel organ differentiate into ameloblasts and progressive differentiation into ameloblasts continues down the sides of the enamel organ. At the same time, mesenchymal cells adjacent to the ameloblast differentiate into tall columnar odontoblasts and begin forming dentine prior to the ameloblasts beginning to lay down enamel.

Ameloblast differentiation stops at what will become the cemento-enamel junction, however, the ring-shaped enamel organ rim continues to proliferate as Hertwig's epithelial root sheath. The adjacent mesenchyme continues to differentiate into odontoblasts. The root sheath separates from the dentine, allowing the mesenchymal cells from the dental sac to deposit cementum on the outer surface of the dentine. As cementum is laid down, it traps the collagenic fibres of the developing periodontal ligament.

At the appropriate time, tissues between the tooth and the oral cavity are resorbed as the tooth begins its migratory eruption path.

Tooth Eruption

Eruption may be defined as the axial or occlusal movement of a tooth from its developmental position within the jaw to a functional position in the oral cavity. It appears that eruption continues throughout life, albeit at a much slower rate in adult years. Eruption may be arbitrarily divided into two stages, pre-functional tooth movement and post-functional tooth movement. Achievement of the functional position in the oral cavity marks the transition from the pre-functional stage to the post-functional stage. Pre-functional eruption may be subdivided into intra-osseous and extra-osseous phases, depending upon the position of the tooth germ in relation to the alveolar crest.

Smith (1980) reported that there was an active phase of eruption which gave way to a less active phase, both phases being of variable time frame. Eruption rate varied from individual to individual, and from tooth to tooth within the same individual. The most rapid rate of eruption was .32mm/week of a mandibular second premolar. The rate of occlusal movement is maximal at the time of gingival emergence. Thereafter, the eruption rate slows as the tooth approaches the occlusal plane and

comes under the influence of masticatory and other intra-oral forces. (Burke and Newell (1958)).

As a general principle eruption begins after mineralization of the crown of the tooth and is accompanied by root formation and resorption of bone or deciduous tooth roots which lie in the eruptive path. Eruption toward the occlusal plane does not begin before the completion of crown formation and the initial root formation of approximately 2-4 millimetres at the expense of basal bone, however, further root formation occurs with rapid eruption. (Carlson (1944)).

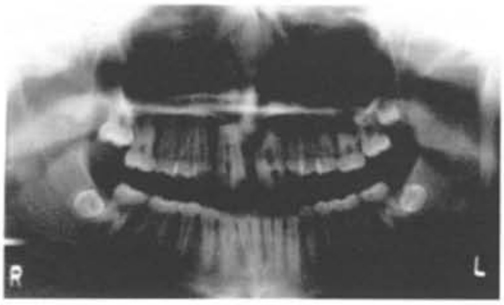

Fig. 1. Demonstrates developmental problems which can occur due to the proximity of the permanent tooth bud to the deciduous precursor tooth. This is a copy of a panoramic radiograph of a 14 year old girl who stumbled and fell at 3 years of age and displaced 61. This led to the dilaceration of 21 root.

The permanent tooth germs assume a position lingual or palatal to their deciduous precursors. This proximity of the permanent tooth germs to the deciduous teeth has importance when intrusive injuries to the deciduous dentition occur, affecting crown or root formation of the permanent successor or leading to an aberrant eruptive path of the permanent succedaneous tooth. (Bhaskar (1980)). (Fig. 1)

Possible Mechanisms of Tooth Eruption

The mediating factors of tooth eruption and their regulation are not well understood. Intra-osseous and extra-osseous phases of eruption may be mediated differently. Research accomplished to date has not clearly defined the process of eruption, and difficulties in conducting research in this area further cloud this issue. Most research has been conducted on experimental animals, particularly rats and rabbits, because of the rapid continuous eruption exhibited by these animals. This data has then been extrapolated to the human dentition. Also, there are a great number of different tissues and cell types involved in the eruption process. Hence, there is some difficulty in isolating a particular tissue or cell type when attempting to evaluate its role in eruption.

There are, at this stage, several hypotheses regarding the mechanisms for eruption of human teeth and their regulation. Because no single contributing factor has surfaced as initiating eruptive force, it has been suggested that the mediators for the eruption of human teeth are multifactorial in nature and act in combination. This may explain the confusion present when evaluating reports in the literature which have investigated these factors individually.

Considerable evidence suggests the precursor of the periodontal ligament, the dental follicle, mediates intra-osseous eruption and the periodontal ligament mediates post-functional tooth eruption. Eruption, but not root growth, is halted if either part of the dental follicle is removed. (Marks and Cahill (1987)).

It was found that irradiated developing teeth in Rhesus monkeys continued to erupt despite a lack of root formation, pulpal proliferation and periodontal ligament. Most crowns erupted, albeit at a retarded rate, and the

dental follicle did not differentiate into the periodontal ligament but maintained its attachment to the cemental surface of the crown. (Gowgiel (1961))

Exactly how the dental follicle mediates intra-osseous eruption is still being unravelled. There is an influx of mononuclear cells prior to eruption in the coronal dental follicle which have been demonstrated to be osteoclasts or their precursors. Also, there is a dramatic increase in these tartrate-resistant, acid phosphatase positive cells, indicating osteoclastic activity during the period of maximal bone resorption. (Marks *et al* (1983) Wise *et al.*, (1985) Marks and Grolman, 1987)).

There is a change in polypeptide composition and increased activity of matrix metalloproteinases within the dental follicle in association with the eruptive process. One polypeptide, labelled DF-95, underwent fragmentation at the onset of eruption and appears to be a 'flag', indicating the onset of the eruptive process. It was hypothesized that the degenerating enamel organ activates the follicular metalloproteinases to breakdown DF-95. (Gorski *et al.*, (1988)).

During eruption in the basal half of the dental follicle there is accelerated cell proliferation and bone deposition in the wake of the erupting tooth. Apical bone formation continues to occur in some teeth once the functional occlusal plane is reached with large numbers of osteoblasts in the basal part of the bony crypt containing the tooth follicle. (Marks *et al.*, (1983)).

Epidermal growth factor, a known mediator of cellular proliferation, has been shown to accelerate incisor emergence in newborn mice (Cohen (1962)). In the rat, epidermal growth factor has been identified in the mesenchymal tissue at the apical foramen, in arteriole walls, in epithelial cells of the cervical loop area and in the tissue surrounding the root sheath epithelium but not in pulpal tissue, odontoblasts or ameloblasts. In the human premolar there was heavy uptake in the dental follicle but not in pulpal tissue, implicating the dental follicle as playing an important role in tooth eruption. (Thesleff *et al.*, (1987)).

In contrast, it has been suggested that cellular proliferation at the fundus of the developing tooth can generate an eruptive force. With growth, the tissues at the fundus of the restrained rabbit incisor will resorb surrounding bone. (Ness (1956)). The work of Kiely and Domm (1977) suggested cortisone accelerated eruption by increasing cell proliferation at the fundus. Teng *et al.*, (1989) accelerated the eruption of rat incisors by administrating cortisone intramuscularly, but did not accelerate the eruption of rat incisor teeth after root resection and removal of the growing end and crown amputation to allow unimpeded eruption had been carried out. This led the authors to speculate that the intact fundus does generate an eruptive force.

Although an eruptive force may be generated in the basal tissues by cellular proliferation, bone resorption, possibly mediated by dental follicular cells, is required for eruption to occur. Using the model of the osteopetrotic rat, it was found that tooth formation occurred but that tooth eruption was inhibited by the decreased bone resorption characteristic of osteopetrosis. (Marks (1976))

The periodontal ligament has been found to be an important mediator of post-functional eruption with three main mechanisms by which the periodontal ligament generates the eruptive force. These are, contraction of the periodontal

ligament due to fibroblast activity, collagen constriction, or tissue fluid hydrostatic pressure (Berkowitz and Thomas(1969)).

Fibroblasts have been shown to be both contractile and motile. (Beertsen, Everts and van den Hoff (1974), Zajicek (1974), and Perera and Tonge (1981)) and the combination of migration and contraction develops an eruptive force within the periodontal ligament. Fibroblasts in the periodontal ligament moved incisally in synchrony with an erupting incisor, but this movement stops as eruption is impeded (Beertsen and Hoeben (1987) with a decrease in production and number of fibroblasts (Michaeli *et al.,* (1986)).

It is thought that collagen constriction may also generate an erupting force. Extracellular matrix and collagen fibres also shifted incisally with tooth eruption. Application of lathyrogens to erupting teeth decelerating eruption lends weight to the hypothesis that collagen constriction is an important factor in generating eruptive force, as lathyrogens inhibit the formation of crosslinks in collagen (Beertsen and Everts (1977) and (1981)).

Historically, the generation of eruptive force has been linked with hydrostatic pressure. Constant (1896) first hypothesized that the blood pressure exerted in the vascular tissue lying between a developing tooth and its bony surrounds is the active mechanical factor in the eruption of teeth. More recently it has been suggested that increased permeability of the periapical periodontal vascular bed results in increased fluid effusion, generating an eruptive force. Radiolabelled material extravasated in the periapical area of erupting teeth has been demonstrated. (Magnusson (1968) (1973))

A tissue fluid hydrostatic pressure hypothesis has also been proposed. Connective tissue ground substance placed in the correct electrolyte medium can expand rapidly and exert pressure against any physical barrier. The administration of hexamethonium, which increases tissue fluid pressure, will extrude rabbit incisors, whereas noradrenaline, which decreases tissue fluid pressure, will intrude rabbit incisors (Moxham (1979)). It has been postulated that interstitial fluid pressure mediates a more rapid phase of tooth eruption whilst the periodontal ligament mediates a slow continuous rate of eruption (Aladdin and Burn-Murdoch (1985)).

In conclusion, it appears that the dental follicle is important for intra-osseous eruption to occur, as is the periodontal ligament important for extra-osseous eruption. The mechanisms by which the various cellular elements interract and are controlled, however, is not well understood.

Factors Influencing Eruption After Gingival Penetration

As well as the eruptive force generated by the erupting tooth, the mechanisms of which are as yet unclear, there are factors which may effect the rate of eruption of the tooth such as forces exerted by the tongue, lips and cheeks, and the opposing dentition on closure of the mandible. Light, continuous forces from the tongue at rest are considered important modulators of eruptive movements. Long faced adults have a decreased biting force at maximum effort when compared with normal adults and this may lead to increased eruption in long faced individuals. (Proffit, Fields and Nixon (1983) Steedle and Proffit (1985))

Further eruption can occur with increased alveolar bone growth. Movement of the teeth in an occlusal direction occurs in conjunction with increases in height of the alveolar processes. When facial growth has slowed in adulthood and a relative equilibrium is

achieved, continued eruption occurs very slowly, however there are small increases in lower facial height in adulthood and eruption continues to occur. (Ainamo and Talari (1976a) (1976b)) In both males and females, there is a significant but small increase in the distance between the cemento-enamel junction and the mucogingival junction from the ages of twenty-three to forty-three resulting from a coronal shift of the cemento-enamel junction rather than an apical shift of the mucogingival junction. Lower face height increases in the order of 0.3mm per year decreasing to an average of 0.02 mm per year, at the age of seventy. A gradually decreasing eruptive rate continues to compensate for facial growth into middle age (Talgren (1957), Sarnas & Solow(1979)).

Some decrease in vertical face height may be expected to occur where occlusal attrition is marked, as the degree of attrition outweighs the compensatory continued eruption of teeth. (Murphy (1959))

Periodontal fibres may be rate-limiting factors with regards to the continued eruption of teeth. Reitan (1959) and Edwards (1970) have both shown that periodontal fibres remain attached to the tooth when the tooth is artificially displaced and the periodontal fibres resist re-alignment over many months. If periodontal fibres do have an inhibitory effect on eruption, it would be expected that periodontally involved teeth may erupt at a greater rate, particularly if these teeth remain unopposed.

Timing of Eruption

The timing of the eruption of teeth and the timing of orthodontic treatment are closely linked. The prediction of eruption for the canine teeth is useful because certain malocclusions may be treated with reference to the anticipated time of eruption of the maxillary canine teeth. The maxillary permanent canine tooth frequently erupts after the premolars and incisor teeth and in a crowded situation the canine can erupt high up in the buccal sulcus with a lack of attached gingiva. If a severe crowding problem is predicted, in some circumstances the maxillary first premolar teeth could be extracted at the appropriate time to minimize space loss. The maxillary canine tooth may then erupt into a more acceptable position, with a greater width of attached gingiva.

Forecasting the eruption of the maxillary and mandibular premolar teeth, particularly the second premolar teeth aids in determining the beginning of orthodontic treatment to prevent forward movement of the permanent first molar teeth into the so called *'leeway'* space.

The landmark studies linking tooth eruption and chronological age are those of Logan and Chronfeld (1933) and Schour and Massler (1941) with the well-known charts of calcification and eruption.

Several studies have attempted to establish Australian norms for tooth eruption: Halikis (1961a, 1961b, 1961c, 1962) based on a cross-sectional study of 862 children in Fremantle; Carr (1962) based on a modified longitudinal study of 1751 teeth of boys and 1752 teeth of girls and cross-sectional study of 1981 boys and 1971 girls in Canberra; Gates (1964) based on a cross-sectional study of 2907 boys and 2753 girls aged 6-15 years in New South Wales in 1954-55; and Harris and Sullivan (1960) based on a small sample of 82 institutionalised children at Bowral in New South Wales.

The results of Gates (1964) are reproduced on page 8 as a representative example. Although the median figures given by Gates offer some guide for the clinician, it is important to note that there will always be

some individuals who do not fit the usual pattern. The use of the 95% confidence interval, by definition, means there remain outliers from the range quoted in 5% of cases.

Sequence of Tooth Eruption

There is considerable variation in the reported sequence of eruption of permanent teeth. The sequence of the eruption as reported by Sturdivant, Knott and Meredith (1962) was 6-1-2-4-3-5-7 in the maxilla in 26% of cases and 6-1-2-4-5-3-7 in 23% of cases. In the mandible it was 1-6-2-4-3-5-7 in 18% of cases, and 1-6-2-3-4-5-7 in 16% of cases. Nanda (1960) reported the most common sequence of tooth emergence as 6-1-2-4-3-5-7 in the maxilla and 1-6-2-3-4-5-7 in the mandible. Lo and Moyers (1953) reported the sequence of 6-1-2-4-5-3-7 in 49% of cases in the maxilla and in the mandible 6-1-2-3-4-5-7 in 46% of cases. It was also noted that classification of the occlusion varied the sequence of eruption. It was found that in 91% of class 1 occlusions the standard eruption sequence of 6-1-2-4-5-3-7/6-1-2-3-4-5-7 combination occurred. In the overall sample, however, this standard combination occurred in only 32% of cases.

Because of the variation in sequence of eruption, each individual patient should be monitored and decisions should be made regarding orthodontic treatment planning on a knowledge of the individual patient's eruptive pattern.

Dental Age

The concept of dental maturity has developed as a method of measuring the dental development of an individual because of inherent inaccuracies in relying upon clinical emergence data. It is difficult to define the precise time of eruption into the oral cavity. There is also a scarcity of data during periods where few teeth erupt, and variation in the timing of eruption can occur due to local factors such as the premature loss of deciduous teeth or the presence of supernumerary teeth. Demirjian and Goldstein (1976) have revised a system for assessing dental maturity, based on a French Canadian population involving assigning different developmental stages to radiographs of 7 or 4 left mandibular teeth. Each tooth is given a score and these scores are added together to provide a maturity score which is referred to a centile chart for conversion to a dental age. One drawback of this system is that there are no Australian standards for dental maturity evaluation, and ethnicity may be a variable affecting tooth eruption.

Some correlation between dental age and chronological age has been reported, but dental age has not been significantly linked with any other index of maturity. Demirjian *et al.*, (1985) found a low association between skeletal maturity assessed using hand and wrist radiographs, somatic maturity assessed using height measurements, and sexual maturity and dental maturity, but dental maturity was subject to less variation than these other measures of maturity in relation to chronological age.

The state of root formation and tooth emergence are closely linked, more so than chronological and skeletal age with dental age of the child (Gron (1962)).

NORMAL OCCLUSION

Once the teeth have erupted into the oral cavity, teeth are viewed as individual entities which collectively form the dental arches. Occlusion can be defined as contact between the upper and lower teeth on closure of the mandible.

Table 1 - Median ages of eruption of permanent teeth of New South Wales children

Tooth*		Females			Males		
		Median	Confidence interval_		Median	Confidence interval_	
			Lower limit	Upper limit		Lower limit	Upper limit
		Year	Year	Year	Year	Year	Year
Upper							
1.	L	6.80	6.714	6.892	7.12	7.043	7.205
	R	6.79	6.702	6.882	7.10	7.018	7.181
2.	L	7.75	7.666	7.828	8.15	8.066	8.228
	R	7.77	7.694	7.856	8.15	8.072	8.235
3.	L	10.71	10.60	10.81	11.33	11.23	11.43
	R	10.65	10.55	10.76	11.31	11.21	11.41
4.	L	9.80	9.691	9.903	10.20	10.09	10.31
	R	9.83	9.722	9.929	10.25	10.14	10.36
5.	L	10.66	10.54	10.78	10.95	10.84	11.07
	R	10.66	10.54	10.77	10.98	10.87	11.09
6.	L	6.11	5.909	6.314	6.23	6.077	6.393
	R	6.13	5.940	6.327	6.32	6.160	6.490
7.	L	11.75	11.65	11.86	12.12	12.01	12.22
	R	11.74	11.64	11.84	12.12	12.02	12.23
Lower							
1.	L	5.94	5.678	6.206	6.21	6.063	6.370
	R	5.96	5.721	6.202	6.16	6.004	6.324
2.	L	6.97	6.867	7.064	7.36	7.280	7.436
	R	6.88	6.782	6.977	7.32	7.236	7.396
3.	L	9.40	9.309	9.490	10.48	10.39	10.58
	R	9.41	9.316	9.497	10.51	10.41	10.60
4.	L	10.12	10.01	10.22	10.79	10.67	10.90
	R	10.30	10.19	10.42	10.82	10.71	10.94
5.	L	11.17	11.05	11.30	11.59	11.47	11.72
	R	11.03	10.91	11.15	11.55	11.43	11.66
6.	L	5.85	5.564	6.159	6.14	5.961	6.232
	R	5.95	5.712	6.206	6.12	5.944	6.304
7.	L	11.25	11.15	11.36	11.63	11.53	11.73
	R	11.30	11.19	11.40	11.69	11.58	11.78

* Tooth code: Teeth are numbered 1 to 7 corresponding to central incisor to second permanent molar. L-and R denote left and right sides of the arches respectively.

_ Ninety-five per cent, confidence interval of the median. (Gates,1964)

Angle (1906) wrote that 'occlusion is the basis of the science of orthodontia.' The shapes of the cusps, crowns and roots and even the very structural material of the teeth, and their attachments are all designed for the purpose of making occlusion the one grand object' and this is still the case today, with correct occlusion being a major objective of orthodontic treatment.

The human occlusion is a dynamic phenomenon, as Begg (1954) wrote 'correct occlusion is not a static occlusion..... but a changing functional process undergoing continual modification and adjustment during the whole life of both deciduous and permanent dentitions'. Continued tooth eruption and facial growth throughout life induce physiologic changes in occlusion. This would indicate that arch dimensions undergo some modification throughout the life of the dentition, to a greater or lesser extent.

There is no generally acknowledged definition of arch length, which is difficult to define specifically. It is a measurement of the space available along the curve of the dental arcade and arch perimeter, arch depth, arch breadth and the Curve of Spee should be taken into account when quantifying this available space. Brader (1972) describes dental arch form as 'a curve described by the position of the tooth crowns in the jaw'. It is difficult practically to determine what curve is to be measured when the teeth are malaligned. An arch length measurement taking into account the space required to align malposed teeth must be separated from the arch length meausrement which is quantifying existing space.

It is anticipated that with modern digitising and video procedures and subsequent computer analysis, arch length will be analysed in the future more accurately in three dimensions than before. To date most published works do not have the benefit of computer aided arch analysis and there are a plethora of methods available to measure arch dimensions, generally upon study casts.

The traditional method of measuring arch length is the brass wire method described by Carey (1958) where brass wire is bent to lie over the incisal edges and proximal contact points of the posterior teeth to the mesial surface of the first permanent molars.

Extensions of the brass wire method have been developed such as the catenometer of Musich and Ackerman (1973) and the plastic template of White (1977). These techniques measure the arch length of a particular dental arch by comparison with a series of calibrated ideal arch forms. The ideal arch forms used were the the catenary curve of MacConaill and Sher (1949) and the Brader (1972) trifocal ellipse. Specialist computer programs designed to analyse space requirements in dental arches are a further extension of the original brass wire method, as direct occlusal measurements are compared mathematically with an ideal arch form.

To remove the problem of subjectivity when utilising an average arch form, segmental arch measurements have been used by various workers and a number of terms are used to describe the measurements obtained. Bishara *et al.*, (1989) used segmental arch measurements to measure 'arch length', Moorees and Chadha (1965) with a similar segmental technique obtained 'arch distance', and Hunter and Smith (1972) again using a similar segmental method for determining 'arch perimeter'. Sinclair and Little (1983) defined arch length slightly differently, using a single straight line. Segmental arch method measurement has the advantage of being

reproducible and any irregularities in arch form can be ignored. Its disadvantage is that a straight line is used to represent what is generally accepted to be a curve or arch.

Arch depth is variously measured from designated points along a perpendicular line bisecting an arch width measurement. Arch depth is an inexact measurement of available space in the dental arcade, but as it is more easily measured is often quoted in research studies.

Changes in arch depth are only a coarse indicator of changes in arch length and do not have its clinical relevance.

Several measurements are used to record arch width. The intercanine width is defined as the length of a line extending from the cusp of one canine to the other on the contralateral side. Similarly, the intermolar width and the interpremolar width measure the length of a line extending from the respective reference points of one tooth to the tooth on the contralateral side.

A number of studies has been conducted on arch dimension changes which occur in conjunction with the development of the dentition. The main difficulty with comparing these studies is the non-uniform reference points used by different research workers.

Arch Dimension Changes with Age

The findings reported by Sillman (1961) give an indication of what can be expected as physiologic changes in occlusion. Mean curves were produced for canine length and width, and molar length and width in the mandible and the maxilla. A composite mean pattern of the dental arches from 0-20 years for each sex was also constructed to form a concept of mean dimensional changes. Canine length increased with age, most rapidly from birth to 4 years and then ceased to change from 12-16 years. From 16-20 years there was a decrease. The molar length, in contrast, increased in all age groups, the period of greatest increase being from 4-8 years. The canine width demonstrated the largest increase from 0-4 years, continued to increase at a slower rate until 12-16 years, and at 16-20 years there was no significant change, although small decreases were recorded. The molar width increased from 4-16 years at a varying rate, but from 16 years of age onwards there was no significant evidence of change.

Richardson and Castaldi (1967) further investigated the rapid alveolar growth which occurs between 0-2 years of age and found very little growth in the anterior region of the maxillary and mandibular arches. The authors concluded this small amount of anterior growth indicated there was sufficient space for the eruption of the deciduous anterior teeth at birth. The posterior arch dimensions increased more than the anterior arch dimensions, indicating the deciduous molar teeth were accommodated by post-natal growth as space at birth was inadequate. Approximately one half of the maxillary posterior arch dimension increase occurred between 0-6 months of age, whilst during the same period there was a smaller increase in posterior arch length in the mandible indicating that the mandibular alveolar growth lagged behind.

Intercanine Width

There is much emphasis placed on the intercanine width in orthodontic practice because of the direct bearing any change in the distance between the canine teeth has on the alignment of the anterior teeth. The distance between the canine teeth is simple to measure and changes in this dimension can be monitored readily. The degree to which anterior crowding may be relieved by lateral alveolar growth and the rationale for

maintaining the initial intercanine width during orthodontic treatment are the major orthodontic implications for monitoring changes in the intercanine width.

It is generally accepted that the intercanine width can be expected to increase in the lower arch until the full eruption of the lower permanent canine teeth and that there is only a slight increase in the upper intercanine width when the upper permanent canine teeth erupt. It would appear that the major changes in intercanine width related to lateral alveolar growth are usually largely completed by the time of the full eruption of the permanent incisor teeth. However, this can only be considered a rule of thumb for which there will be individual exceptions. Dental age does not correlate well with other means of measuring growth such as skeletal age, and so in an individual with accelerated eruption of teeth, further lateral growth may occur to accommodate crowded lower teeth.

In contrast, a contraction of the intercanine width with time in late adolescence and early adulthood is generally accepted. There is also a concomitant decrease in arch length which is attributed to the take up of the leeway space and a generalised mesial movement of the dental arches. (Sinclair and Little (1983), Siatowski (1974), Moorrees, Lebret and Kent (1979)).

These findings give the picture of a dental arch which expands whilst alveolar growth is occurring and teeth are erupting, but which contracts over time at maturity with arch dimensions decreasing. There is, however, a great deal of individual variation, so while the mean findings of various research papers report a decrease in arch dimensions, certain individuals may well demonstrate an increase in arch dimensions on maturity. It must also be stated that this generalised decrease in arch dimensions with maturity is small compared with the increase in arch dimensions which occurs with alveolar growth during childhood and adolescence.

Common Occlusal Traits of the Developing Dentition

There are several occlusal traits commonly found in the developing dentition which disappear as the dentition matures.

Spacing in the Deciduous Dentition

If the ideal deciduous dentition is visualised a degree of spacing between the anterior teeth would be desirable, so that sufficient arch length is available for the eruption of the wider permanent anterior teeth. Spacing in the posterior region would not be considered necessary because the deciduous molar teeth generally have a greater mesio-distal diameter than the succedaneous teeth. This is the so-called *leeway space.*

Baume (1950a) described 'spaced' and 'closed' deciduous dental arches. The spacing frequently occurred between the mandibular deciduous canines and molars and the maxillary deciduous lateral incisors and canines and he coined the term 'primate spaces' (*Fig. 2*). He also found conversion from closed to spaced dentitions did not occur in the study population examined late in the deciduous dentition. There was very little change in arch length on full eruption of the deciduous dentition, and only minor changes in transverse dimensions.

Fig. 2. Primate spaces in the mandibular arch of a 2 year old.

This is consistent with Moorees *et al.*, (1979) who found arch breadth did not change greatly in individuals of 4-6 years dental age. Moyers (1969) held it was a popular misconception that spacing between deciduous teeth continually increased over the life of the deciduous dentition as, on the contrary, spacing remained relatively constant after the full eruption of the deciduous dentition.

Little spacing between the deciduous teeth indicates that crowding of the anterior permanent teeth may follow, but there is evidence to suggest that this is not necessarily so (Moorrees and Chadha (1965)). Baume (1950c) reported that 40% of 'closed' deciduous arches went on to have favourable permanent incisor alignment. It would seem in these instances, with all other factors being equal, growth of the alveolus 'caught up' to such a degree as to accommodate the permanent incisor teeth.

Central Diastemata

It would seem from epidemiological surveys conducted some years ago that spacing in the deciduous and mixed dentition is common, but much less common in the full permanent dentition. Gardiner (1956) studied 1000 Sheffield school children and found the prevalence of median diastema to be 46% at 6 years, dwindling to 7% at 15 years. Weyman (1967) found a midline diastema of greater than one millimetre in 56.8% of subjects with only the upper permanent central incisors erupted, 38.0% of subjects with the upper permanent central incisors and lateral incisors erupted and 7.4% of subjects with upper permanent incisors and canines erupted. In the great majority of patients therefore, spacing, in particular a central diastema, can be considered a physiologic state, which disappears with the normal development of the occlusion.

It would seem wise to delay orthodontic treatment for central diastemata until the full permanent dentition is attained as most of these will close. However, there remain central diastemata which are excessive in size, and do not close up with occlusal development. It would be advantageous to identify these central diastemata in advance so that interceptive orthodontic treatment could be instigated, but at this stage this would only be possible at an empirical level. *(Fig. 3 and 4).*

Fig. 3. A central diastema in recently erupted upper deciduous incisor teeth in an nine month old baby

Fig. 4. A central diastema remaining in a 34 year old woman. The factors which cause diastemata to remain open and not close on attainment of the full permanent dentition are not well understood.

Leeway Space

There are two methods of adjustment of the lower first molar tooth to erupt in a class

I occlusion. These are; the closure of primate spaces with pressure in a mesial direction from the erupting first permanent molar, and the taking up of the leeway space. Baume (1950abc)

On eruption, the first permanent molars move the deciduous second molar and first molar mesially to close the primate space distal to the canine and create a Class I posterior interdigitation.

In subjects where there may be no space in the primary dentition, or a straight terminal plane the mesial movement of the lower first molar may occur at a later stage when the second deciduous molar is shed. This mesial movement of the lower first permanent molar takes up the 'leeway space' or the additional mesio-distal width of the second deciduous molar.

Mesial shifting of the maxillary first molars on exfoliation of the second deciduous molars also occurrs. However, if molar intercuspation occurrs prior to premature loss of deciduous molar teeth in either arch, minimal mesial movement of the permanent molar teeth is evident (Moorees *et al.*, (1979)).

It must be acknowledged there is a wide degree of individual variation in the sequence of events mentioned above. Lavelle (1968) found that permanent premolar teeth may be larger than their deciduous precursors. Caries of deciduous teeth or hypodontia of permanent premolar teeth may also affect the position of the first permanent molar tooth.

The Ugly Duckling Stage

The ugly duckling stage occurs when pressure of the erupting maxillary permanent canine teeth causes a transient distal crown inclination of the erupted maxillary permanent lateral incisor teeth.

Fig. 5. This is a panoramic tomogram of a patient who avulsed the upper left incisor and had a rigid splint in situ for three months during the ugly duckling stage of development. The right canine tooth was further advanced in eruption than the left canine tooth. Resorption of the upper right lateral incisor tooth occurred whilst this tooth was held rigidly.

Although little is written regarding the ugly duckling stage of development, it must be taken into consideration when planning concurrent orthodontic treatment as resorption of lateral incisor roots can occur if the upper lateral incisor teeth are held rigidly in place *(Fig. 5, 6 and 7).*

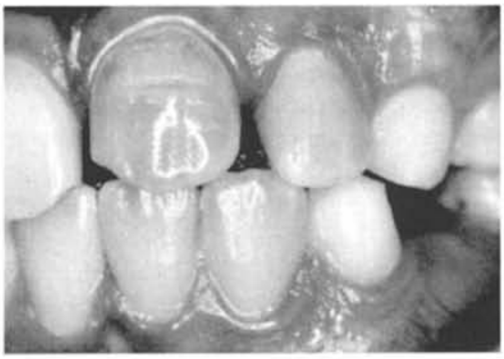

Fig. 6. The upper left canine caused distal movement of the upper left lateral incisor crown after the splint was removed compared with the upper right lateral incisor tooth in Fig. 7.

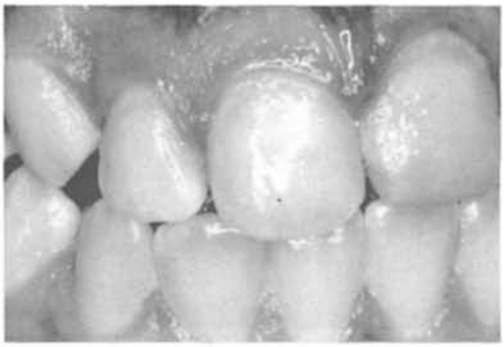

Fig. 7. The upper right lateral incisor tooth.

Late Anterior Crowding

While there is generally a decrease in arch length with maturity of the permanent dentition, several workers have also described an increase in crowding of the upper and lower teeth in late adolescence and early adulthood (Bjork and Skeiller (1972) Sakuda *et al.*, (1976) Leighton & Hunter (1982) Miethke and Behm-Menthel (1988) Sinclair and Little (1983) Lunstrom (1969)). However, no single factor has been isolated as a predictor for crowding in the maturing permanent dentition. Although vertical growth is associated with a tendency for retroclination of the lower incisors and horizontal growth with proclination of the lower incisors, there is no evidence to link growth pattern with an increase of crowding in the later permanent dentitions. (Lunstrom (1975)) Subjects with a tendency to increased lower facial height and a vertical growth pattern had a statistically significant increase in late mandibular crowding. Sakuda *et al.*, (1976). It appears that lower incisor crowding manifests itself in differing skeletal morphologies independent of lower incisor position.

Lower Third Molars and Crowding

The relationship between late anterior crowding and the eruption or impaction of third molar teeth has also been analysed.

It was noted last century that the wisdom teeth are frequently the immediate cause of irregularity of the teeth by the pressure exerted toward the anterior part of the mouth. In contrast, Bishara and Andreasen (1983) conclude, there is no conclusive evidence to indict third molars as the major aetiologic agent in lower incisor crowding.

There appears to be no specific cause and effect relationship isolated between lower anterior crowding and the presence of third molars, but the presence of third molars is associated with a decreased arch perimeter and a generalized increase in crowding over the whole arch.

If the eruption of third molar teeth does lead to a decrease in arch length, it is unclear whether it is impaction of the third molar teeth or merely a mesial eruptive force of emerging third molars where sufficient space is available which leads to a decrease in arch length.

Bergstrom and Jensen (1960) studied the dental casts of 60 dental students, 30 of whom had unilateral agenesis of the upper third molars, 27 had agenesis of the lower third molars and three had one third molar either missing or lost. The results suggested that there was more crowding in a quadrant with a third molar present than in a quadrant with a third molar missing.

Clinically indicated removal of the third molar may therefore ameliorate generalised arch perimeter loss but not necessarily decrease anterior crowding. Lindquist and Thilander (1982) randomly selected 52 patients with unilateral removal of lower third molars who had received no orthodontic treatment to the lower jaw. Annual recordings for at least three years were subsequently taken. The results indicated a more favourable arch development in the extraction side than the control side for 70% of cases.

It would seem that anterior crowding *per se* may not be related to third molar eruption but that general decrease in arch perimeter may be linked to third molar eruption.

Orthodontic Treatment and Maturational Arch Dimension Changes

An important clinical implication of studying arch dimension changes that occur with time in untreated subjects is predicting outcomes after orthodontic treatment and delineating appropriate retention regimens. Orthodontic therapy may temporarily alter the course of physiologic change in the occlusion, for a time even reverse this; but following mechanotherapy the developmental maturation process resumes (Bishara *et al.*, (1989)).

Glenn, Sinclair and Alexander (1987) investigated arch dimension changes post-orthodontic treatment examining 28 non-extraction orthodontic cases with acceptable results at least three years out of retention. Arch length, arch width, and a number of cephalometric variables were analysed as shown.

Arch length increased in 50% of the cases in the sample during treatment but this increase was not statistically significant. Arch length decreased significantly postretention in 96% of cases, resulting in a mean arch length decrease of 2.2mm. Similarly, the intercanine width was increased in 68% of cases during treatment but this increase was not statistically significant. Intercanine width decreased significantly postretention in 89% of cases, resulting in a mean intercanine width decrease of 1.0mm. In contrast the intermolar width increased significantly during treatment and decreased insignificantly postretention; overbite and overjet were reduced significantly during treatment and postretention changes were insignificant.

In relation to these factors the lower incisor crowding measured using the irrgularity index reduced significantly during treatment (mean 1.9mm) but a significant postretention increase was noted (1.2mm). The lower incisor was proclined significantly, forward 1.4mm to the APo line, and there was an insignificant change postretention. There was a slight significant opening rotation of the mandible (1.2°) during treatment which became a small but significant closing rotation postretention of 1.4°.

These results would seem to confirm the suggestion of Bishara *et al.*, (1989) that the normal physiologic changes in arch dimension are reversed or retarded during non-extraction treatment and that postretention there is a slight rebound effect, or an unmasking of the normal physiologic changes.

Little, Wallen and Riedel (1981) examined 30 premolar extraction cases and compared pretreatment, postreatment and 10 year postretention records. The mean annual changes in arch length, intermolar and canine width, overbite and overjet and incisor irregularity were compared. (Sinclair and Little (1983)). There was no significant difference in arch length change, but significant differences in mean annual change for the other parameters.

The same group was analysed 20 years postretention and found crowding continued to increase during the 10-20 year postretention phase but to a lesser degree than from the end of retention to 10 years postretention. Only 10% of cases were judged to have clinically acceptable mandibular alignment at the last stage of diagnostic records (Little, Reidel and Artun (1988)).

These results need to be taken into consideration when retention is discussed with orthodontic patients. The concept of

indefinite retention has also developed in order to maintain orthodontic alignment as physiologic changes in arch dimensions occur with age.

There is no suggestion that treatment modality ensures against arch dimension changes and consequent crowding with time. Comparisons between extraction and non extraction cases show no significant differences in the irregularity index (Puneky, Sadowsky and Begole (1984)). Furthermore, proclination of the lower incisor is possible and stable and that proclination of the lower incisor is not subsequently significantly associated with lower incisor crowding. (Glenn *et al.*, 1987)).

CONCLUSION

Much research regarding the development of the dentition and physiologic changes to occlusion was accomplished some years ago. Recent interest is directed towards the late maturational changes which occur in individuals and to the field of cytochemically defining the process of tooth eruption.

While it would seem beneficial to collect updated information on such aspects of occlusal development from the deciduous to permanent dentition with the generalized improvement in dental health observed today, when arch length loss due to caries, restorations and extractions would be less than in the past, the time has probably passed for large scale growth studies. Modern ethics committees may not approve such projects, particularly if radiographs are included for assessing dental age and measuring maturational growth change. The cost of such projects is also likely to be prohibitive.

Our knowlege regarding occlusal development remains incomplete regarding the occlusal changes that occur with the eruption of third molars and long term occlusal changes associated with maturation. New information will probably be obtained by re-working previous growth study data or by conducting small sample growth studies and by utilizing sophisticated computer analysis.

The factors which initiate and regulate tooth eruption require further elucidation and when the eruptive process is fully described ectopic eruption and impactions may be better understood.

All in all, the developmental occlusal changes which occur need to be comprehensively understood before malocclusions can be accurately defined and comprehensively treated.

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2 Aetiology of Malocclusion

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INTRODUCTION

A malocclusion is the result of changes to the normal developmental processes of the skeleton, teeth and soft tissue environments. These variations in tissue development may occur before birth (congenital) or after birth (post-natal) and are influenced by a range of genetic, environmental, traumatic and pathological factors.

It has been estimated that one third of the population of the United States of America has clinically normal occlusion, with the remaining two thirds, exhibiting some manifestation of malocclusion (Proffit 1993). Within this malocclusion group, only one in twelve individuals are able to attribute their malocclusion to a specific causative event or factor. The vast majority of malocclusions, therefore, have indistinct aetiologies, believed to be the result of multifactorial influences on the normal growth and development of facial and oral tissue.

This chapter explores the many aetiological influences occurring during occlusal development. An ability to recognise various aetiological factors in the development of a malocclusion is central to the appropriate timing and treatment for all orthodontic patients.

CONGENITAL INFLUENCES IN THE AETIOLOGY OF MALOCCLUSION

The aetiological influences responsible for a malocclusion which are present at birth are known as pre-natal or congenital factors. At the time of birth these factors may be clinically obvious, as are the defects associated with facial and oral clefting. Alternatively, some congenital influences remain hidden, such as the congenital failure of permanent tooth development, only to be manifested as malocclusion influences in later stages of growth and development.

Congenital factors contributing to the development of a malocclusion can be further classified as genetic or environmental in origin. Genetic or environmental influences can be recognised individually as the primary contributor in the development of a malocclusion, however, the influences of both genetic (hereditary) and environmental factors combine to produce the majority of malocclusions (Moyers 1975, Proffit 1993, Graber and Vanarsdall 1994).

Systemic Genetic and Hereditary Influences

Genetic syndromes and their influence on the malformation of oral and facial structures

are responsible for very few of the total malocclusions observed. Table 1 outlines some of the more common genetic syndromes and their associated facial and oral features (Graber and Vanarsdall 1994).

In the absence of an identified genetic syndrome, the influence of hereditary on the growth and development of an individual is often clinically obvious. The noted physical feature of mandibular prognathism in the Royal German Hapsburg family has been well documented. In more recent times the skeletal and dental developmental similarities which exist between parents and their children have also found positive correlations in a study by Harris and Kowalski (1976).

The question of the magnitude of genetic contribution to a malocclusion continues to be examined in the light of increasing identification of, and investigation into, the human genome. Because the inheritance of facial and oral traits is believed to be controlled by multiple genetic input (polygenic), most studies examining these traits have used twins and triplets, so that inherited characteristics may be identified.

Twins may be monozygotic (identical) or dizygotic (fraternal). The difference between monozygotic and dizygotic twins is in the chromosomal dioxyribonucleic acid (DNA) components possessed by each twin. Monozygotic twins result from the very early division of a single fertilized egg. This means that each monozygotic twin, of a pair, has identical DNA, chromosomal or genetic information. Any differences in physical growth and development of monozygotic twins can be largely attributed to environmental influences.

Dizygotic twins, result from two simultaneously released eggs being fertilized by different spermatozoa. The genetic influence on these twins would be expected to be no more different than that of any other two non-twin siblings. The fact that they share the same uterine environment during gestation, however, means their pre-natal environmental influences are considered to be very similar.

Monozygotic twins, dizygotic twins and non-twin siblings have been studied, so that the influence of hereditary on the development of malocclusion may be more clearly observed.

Occlusal traits are under genetic control (Stein *et al.*, 1956). While up to 40% of dentofacial variations responsible for malocclusion can be attributed to genetic influences (Lundstrom 1984).

More recent studies of twins (Potter *et al.*, 1981), and of first-degree relatives by (Harris and Smith 1980), have indicated an increased finding of the importance of environmental over hereditary influences in the developing occlusion. Some occlusal characteristics, such as overjet, showed little, if any, influence from hereditability in their development (Corrucini, Potter *et al.*, 1980, 1986).

The twin studies of Townsend *et al.*, (1988) confirmed the growing belief that environmental influences contributed more to the observed variability between subjects than earlier twin studies revealed. The genetic components of variance for malocclusion are, from greatest to least, overjet, overbite and molar relationships (Harris and Smith 1980).

The study of family members, other than twins, has also been an accepted method of estimating hereditability influences. Facial skeleton and dental characteristics have been measured and compared between mother and child, father and child and pairs of siblings. High familial tendencies are observed in the Class II and Class III skeletal patterns (Nakasima *et al.*, 1982) and hereditary has a strong influence when predicting facial growth (Suzuki and Takahama 1991).

Table 1 - Syndromes Associated with Oro-facial Disturbances

Syndrome	Aetiology	Oro-facial features	Other features
Treacher Collins syndrome	Autosomal dominant	Mandibular deficiency sometimes with oral clefting	Hypoplastic low-set ears, downslanting of lateral palpebral fissures
Basal cell nevus syndrome (Gorlin syndrome)	Autosomal dominant	Mandibular Prognathism; jaw cysts	Macrocephaly, frontal and biparietal bossing; ocular hypertelorism; multiple basal cell carcinomas; bifid ribs; short forth *metacarpals*
Marfan syndrome dominant	Autosomal	Mandibular Prognathism	Marfanoid habitus arachnodactyly; fusiform and dissecting aneurysms of the aorta
Osteogenesis Imperfecta	Autosomal dominant	Mandibular Prognathism; dentinogenesis imperfecta-like tooth anomalies	Fragile bones; blue sclerae; deafness; loose ligaments
Neurofibromatosis	Autosomal dominant	Craniofacial and mandibular asymmetry	Caf -au-lait spots; neurofibromes; other haematomas and neoplasms; endocrine disturbances; skeletal defects; sometimes macrocephaly; hypertrophy of facial soft tissue
Nager acrofacial dysostosis	Autosomal recessive	Mandibular deficiency, cleft palate	Hypoplastic ears, downslanting of lateral palpebral fissures; some preaxial upper limb deficiency
Robin complex	Aetiologically heterogeneous; Variant: Stickler syndrome is autosomal dominant	Mandibular deficiency / micrognathia, cleft palate, glossoptosis	May be isolated malformation for part of other syndromes, most commonly Stickler syndrome
Hemifacial microsomia (Goldenhar *syndrome)*	Generally sporadic; some familiar examples where *autosomal dominant* recessive inheritance is identified	Facial asymmetry, Mandibular deficiency; micrognathia, hypoplastic mandibular ramus, *variable manifestations of cleft* lip and/or palate	Asymmetrical hypoplastic ears, ear tags, vertebral anomalies, cardiac defects, renal anomalies
Mobius syndrome	Unknown, sporadic	Micrognathia	Bilateral sixth and seventh nerve, palsy prominent, broad nasal bridge, epicanthic folds, limb reduction defects, intellectual disability
Hallermann-Streiff syndrome	Unknown, sporadic	Mandibular deficiency, micrognathia, forward placed mandibular condyles, natal teeth, oligodontia	Short stature, dyscephaly, hypotrichosis, beaked nose, congenital cataracts
Amelogenesis imperfecta	Aetiologically heterogeneous, several modes of inheritance	Anterior openbite, discoloured (hypoplastic) teeth, hypomaturation of hypocalcification of tooth enamel	
Hemihypertrophy	Unknown, sporadic	Facial asymmetry due to hypertrophy of bone and soft tissues. Tongue, mandible and teeth may appear unilaterally enlarged	Hemihypertrophy involving head, limbs and body sometimes associated with Wilms' tumor and adrenocartical carcinomas
Romberg syndrome	Unknown, rare	Facial asymmetry due to hemigtrophy involving muscle, bone and cartilage. Lip and tongue development altered	Left-side predilection, epilepsy, migraine

Harris and Johnson (1991), using the longitudinal Bolton - Brush growth study data, proved a significance in the heritability of skeletal characteristics but a low heritability influence on dental (occlusal) characteristics. The heritability of skeletal influences increases with age, whereas the dental heritability influences decreases with age. The influences of the facial skeleton on the development of a malocclusion is the result of, at least in part, a hereditary component, whereas, dental variations resulting in malocclusions appeares to be under the greater control of environmental factors.

Present day opinion generally supports this combination theory of the influence of genetic and environmental variables on skeletal and dental development (Proffit 1993, Graber and Vanarsdall 1994).

Local Genetic and Hereditary Influences

Disturbances of dental development may occur in isolation of major identifiable syndromes. Because these anomalies are present at birth, even if their influences are not manifested until later growth and development, they are considered to be part of the family of congenital influences in the aetiology of malocclusion.

Congenitally absent teeth

Disturbances to the tooth bud during the early stages of tooth formation, initiation and proliferation, result in the congenital absence of teeth. The complete absence of teeth anodontia is the most severe expression of this anomaly and is often related to an individual displaying characteristics of ectodermal dysplasia. Oligodontia describes the congenital absence of many of the teeth (Fig. 1) and, the most frequent expression of congenital tooth absence hypodontia describes the absence of individual or a small number of teeth (Proffit 1993).

Fig. 1. A severe expression of oligodontia, this 14 year old has only six permanent teeth.

The Field Theory of tooth development explains the usual pattern of hypodontia. This theory describes the development of teeth in 4 fields incisors, canines, premolars and molars. It is postulated that for any given field, the most distal tooth of that field is the most likely tooth to experience hypodontia, for example lateral incisors (Fig. 2), second premolars (Fig. 3) and third molars (Fig. 4). Fig. 5 shows the combination of affected fields with the maxillary lateral incisors and a single maxillary third molar absent in this patient. The canines, being sole members of their field are, interestingly, rarely congenitally absent.

Missing teeth result in the exaggeration of Bolton's discrepancies and therefore in an overall inability for teeth to occlude normally. Their influence on malocclusion development can be minimised if their absence is detected early and long term treatment strategies are planned and enforced.

Supernumerary teeth

During the initiation and proliferation phases of tooth development additional tooth material may form. Beyond the twenty deciduous and thirty-two permanent human teeth, which normally develop, sometimes additional or supernumerary teeth form.

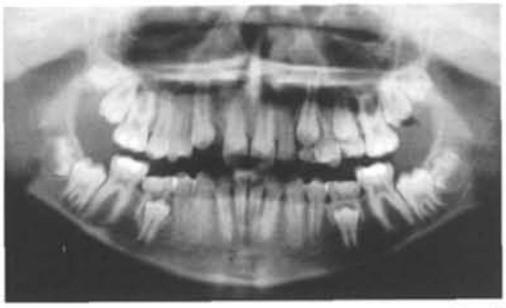

Fig. 2. Hypodontia of the right maxillary permanent lateral tooth.

Fig. 3. Hypodontia showing absence of bilateral mandibular second premolars.

Fig. 4. Hypodontia of left maxillary third molar tooth.

Fig. 5. Hypodontia in multiple fields. Maxillary lateral incisors and the left maxillary third molar are absent.

These teeth are most commonly found in the maxillary midline (mesiodens) (Fig. 6) and in the premolar or third molar regions (Fig. 7). They may affect the normal development of the occlusion through their ability to impede the eruption of underlying and nearby teeth or, by their own eruption, disrupt an otherwise normal Bolton's relationship, resulting in an increase of crowding and/or overjet or a decrease in acceptable buccal interdigitation.

The early detection of these supernumerary teeth, often through routine radiographic investigations of delayed eruption, means that their removal can facilitate the normal progression of tooth eruption and occlusal development.

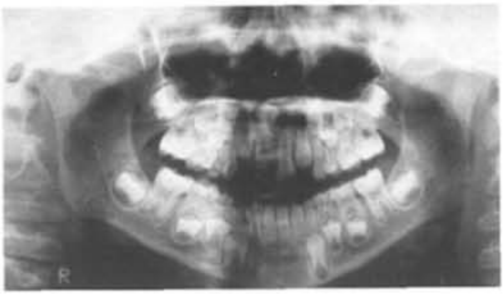

Fig. 6. Three mesiodens (midline supernumerary teeth) were surgically removed from this 8-year-old to assist the eruption of the right maxillary incisor teeth.

Fig. 7. This supernumerary right mandibular molar tooth (49) was removed with the other four third molar teeth.

Malformed teeth

During the histodifferentiation and the morphodifferentiation stages of tooth development the normal size and shape of a tooth is established.

The maxillary lateral incisor teeth are most commonly affected by size malformation traits. The reduced size lateral teeth, known as 'peg laterals' are a factor in the development of some malocclusions. A small maxillary right lateral incisor tooth (peg lateral) may display an abnormal eruption and impede the eruption of the permanent canine (Fig 8). Note also the congenital absence of the left maxillary lateral incisor tooth, a phenomenon often associated with malformation of the contra-lateral tooth.

Fig. 8. The right maxillary lateral incisor tooth (a peg lateral) has moved to impede the eruption of the canine tooth.

Smaller sized teeth can cause occlusal problems as can those which appear larger than normal size. During tooth formation, the union of tooth buds will result in teeth that are abnormally large. These larger than normal teeth may arise as the result of one of two developmental disturbances.

If the correct number of teeth are present in the mouth, then the abnormally large tooth (usually an incisor) is referred to as geminated. This means that the external clefting of the enamel of this large tooth, conceals a single pulp chamber, whereas when two teeth buds fuse (fusion), two distinct pulp chambers will exist. With tooth fusion, there is usually one less tooth present in the mouth, for each fused tooth observed. This is because the single fused tooth is, in fact, the union of two tooth buds. Less commonaly, fusion may occur between a tooth bud and a supernumeracy bud.

Eruption disturbances

Failure of eruption of teeth can occur for a variety of reasons. The permanent tooth can be impeded in its eruption by the presence of supernumerary teeth, dense bone and overlying fibrous soft tissue.

Children with cleidocranial dysplasia experience eruption difficulties through the combination multiple supernumerary teeth, dense overlying bone and fibrous gingival tissues. Normal tooth eruption, for these patients, only follows the surgical removal of supernumerary teeth and excess bone, as well as the excision of overlying gingivae (Jensen and Kreilborg 1990).

The failure of normal deciduous tooth root resorption can delay the eruption of underlying teeth. Ankylosis of deciduous molars occurs in 5% - 10 % of children in the United States of America (Messer and Cline 1980). The decision to remove such teeth depends on the length of retardation of permanent tooth eruption (Proffit 1993). These teeth usually cause no long term occlusal disorders if the permanent tooth has commenced eruption before mesio-distal space loss occurs due to the drifting of adjacent teeth, or the overeruption of opposing teeth (Proffit 1993). Figs. 9 and 10 show the space loss possible with the combination of ankylosis of the deciduous right maxillary second molar tooth, congenital absence of right maxillary second premolar tooth and drifting of the adjacent teeth.

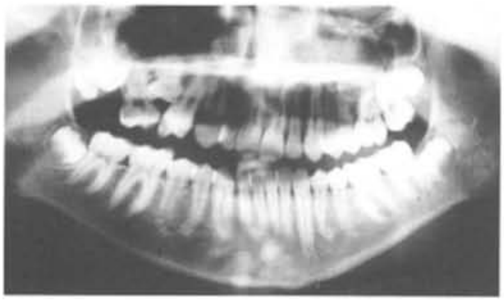

Fig. 9. The congenital absence of the right maxillary second premolar and the ankylosis of the right maxillary deciduous second molar tooth have combined to create a malocclusion in a very localised area of the mouth.

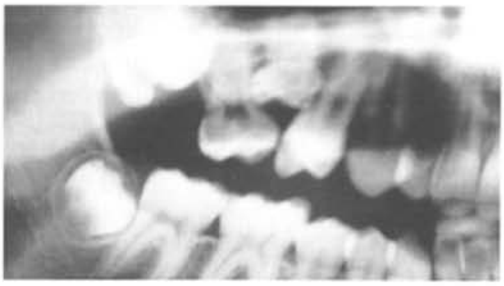

Fig. 10. Closer view of Fig. 9.

Fig. 11. Impaction of the left maxillary canine tooth is a result of insufficient arch space for tooth eruption and the poor positioning of the developing canine tooth bud.

Fig. 12. Ectopic position of left mandibular canine tooth.

Fig. 13. Lateral Cephalometric radiographic view of Fig. 12.

The misplaced eruption (ectopic eruption) of teeth can also result from interference with the normal path of eruption. This may be caused by the initial tooth bud being in an unusual position, (Figs. 9 and 10). Ectopic eruption is most frequently seen in the maxillary arch (Shapira and Kuftinec 1982, Bjorkin and Kurol 1983).

The mandibular lateral incisor is commonly translocated with the adjacent canine tooth, when its tooth bud is ectopically positioned (Brennan *et al.*, 1985). This may lead to problems with lateral occlusal excursion during function, as the teeth have difficulty in finding satisfactory interdigitation.

In general, the impaction or ectopic eruption of canine teeth usually occurs due to insufficient arch space for eruption Fig. 11. However, sometimes the path of eruption of the canine tooth can be disturbed for reasons unknown and the resulting impaction, or ectopic eruption, (Fig. 12 and 13) will prove to be a significant influence on the developing malocclusion.

Primary failure of eruption

Primary failure of eruption (Fig. 14) is the term used to describe the unexplained inability of a tooth, or teeth, to undergo the normal process of eruption. In the absence of other factors which may retard or prevent the eruption of a tooth, sometimes it can be observed that a tooth or teeth just fail to erupt. The aetiology of this anomaly is unknown and attempts to orthodontically reposition these are often unsuccessful.

Fig. 14. This ten-year-old patient showed no improvement in positioning of the right maxillary first molar tooth, over 18 months monitoring and orthodontic treatment. The tooth, with no history of trauma or pathology, was eventually removed.

Systemic Environmental Influences

Within the uterine environment embryological growth and development proceeds according to genetic predetermination and environmental influences. When the development of the orofacial complex of an embryo is disturbed, due to systemic influences on the normal growth processes, changes can occur which may contribute to the alteration of skeletal and/or dental form and, therefore, influence the development of a malocclusion.

Any chemical, viral or microbial agent responsible for the disturbance of the normal development of an embryo is known as a teratogen. The effects of teratogens are usually seen if low concentrations of the agent have influenced the embryo's growth. Higher levels result in lethal consequences for the embryo with the pregnancy usually not proceeding to full term. Proffit (1993) described the following teratogenic agents amongst those known to contribute to the formation of a malocclusion (Table 2).

Table 2 - Teratogenic Agents Associated with Orofacial and Dental Malformation.

Teratogenic Agent	Effect
Aspirin	Cleft Lip and Palate
Cigarette Smoke (Hypoxia)	Cleft Lip and Palate
Cytomegalovirus	Microcephaly, hydrocephaly, microphthalmia
Dilantin	Cleft Lip and Palate
Ethyl Alcohol	Central mid-face deficiency
13-cis Retinoic Acid	Retinoic acid syndrome with associations to some cases of hemifacial microsomia and Treacher Collins syndrome
Rubella Virus	Microphthalmia, cataracts, deafness
Thalidomide	Malformations similar to hemifacial microsomia and Treacher Collins syndrome
Toxoplasma	Microcephaly, hydrocephaly, microphthalmia
Valium	Cleft Lip and Palate
Vitamin D excess	Premature suture closure

A well recognised syndrome *Foetal Alcohol Syndrome* is the result of high levels of ethanol being present during the early stages of pregnancy. Clinically, as these children grow, they display significant maxillary and midface deficiency and may require treatment of their malocclusion throughout and following growth.

Local Environmental Influences

Local factors of pressure and trauma can influence the development of the orofacial tissues during gestation and at the time of birth. Intrauterine moulding is the facial distortion resulting from intrauterine pressure effects during early development (Proffit and Ackerman 1994). The most frequently seen manifestation of this is the Pierre Robin syndrome which, because of the patients tight positioning of the head against the chest during gestation, results in the underdevelopment of the mandible at birth. Pierre Robin syndrome is often associated with palatal clefting. Bull *et al.*, (1990) described this anomaly and the breathing difficulties for the newborn with Pierre Robin syndrome. During childhood growth there maybe some catch up to normal mandibular positioning, however, others who do not experience this growth, remain in need of surgical and orthodontic treatment intervention at later times.

Post-natal Influences in the Aetiology of Malocclusion

Following birth the first twenty years of life sees the growth and development of skeletal, muscle, soft tissue and dental elements of the body. As the patient progresses towards adulthood, various influences can shape the development so that deviations from normal create the basis for the formation of a malocclusion.

Skeletal Growth and Development

The major influences disturbing the expected normal growth and development of the maxilla and mandible are:

Skeletal trauma during growth

The influence of facial deformities at birth, on the potential for normal growth and development, is profound. As discussed, the Pierre Robin syndrome patient rarely recovers full mandibular growth potential during life, without the assistance of surgical and orthodontic intervention.

Comparisons of adults with normal occlusion with untreated unilateral clefts of the maxillae, reveals that the distortion present with the cleft defect was maintained and often accented by growth (Filho *et al.*, 1992). The early surgical intervention for the repair of cleft the lip in cleft lip and palates is a factor influencing malocclusion. The early scarring of the lip tissue prevents the expected downward and forward growth of the maxilla and results in the familiar transverse and anteroposterior development deficiencies seen in maxillary cleft patients. (Figs. 15 & 16).

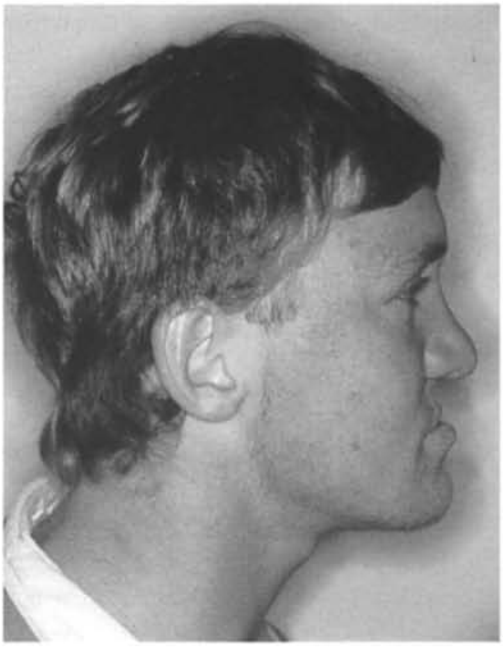

Fig. 15. This 17-year-old, born with a unilateral clefting of the lip and palate, shows typical midface hypoplasia.

Fig. 16. The dentition of the patient in Fig 15. Note failure of development of the transverse and antero-posterior dimensions of the maxilla.

During childhood and adolescence, fractures of the mandible and maxilla also disrupt the normal patterns of growth, however, the most common childhood jaw fracture, that of the condylar neck of the mandible, does not, in 75% of cases, interfere with the potential for normal mandibular growth and development (Bjork 1963). Only 5% of patients presenting with severe mandibular deficiency or asymmetry report a clinical history of early mandibular or condylar fracture (Proffit *et al.*, 1980).

Non-specific skeletal disturbances during growth

Less obvious than a traumatic event, the skeletal development in a growing child can become unbalanced, with no obvious aetiological influence.

The concomitant lack of development in the maxilla and increase of size of the mandible can leave the dental arches uncoordinated with a skeletal and dental Class III malocclusion (Figs. 17 and 18).

Conversely, the 13 year old girl in Fig. 19 shows a convex profile and increased overjet (Fig. 20), typically seen in Class II developmental patterns.

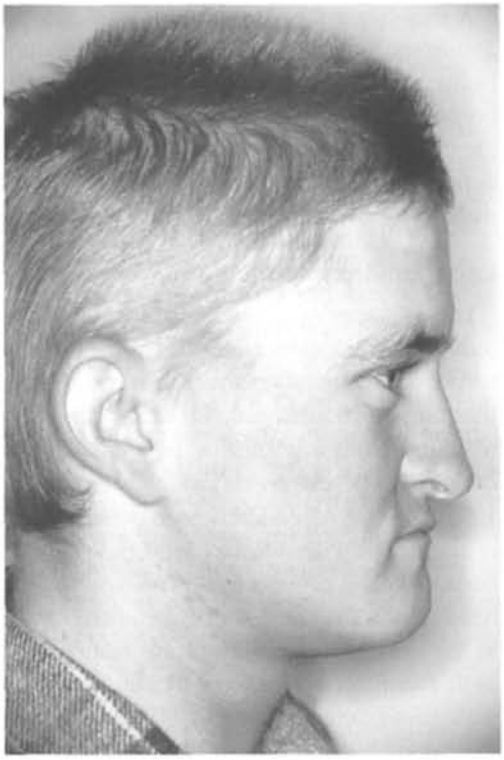

Fig. 17. This 14 year old male exhibits, in profile, typical physical characteristics of a Class III skeletal malocclusion. His short and hypoplastic midface is accentuated by the overdevelopment in his mandibular growth.

Fig. 18. Dental anterior and bilateral posterior crossbites complete the Class III presentation of the patient in Fig 4-17.

Fig. 19. A 13 year old girl with a marked Class II (convex) profile.

Fig. 20. The patient in Fig 4-19 displays increased overjet.

Sometimes the developmental disturbances are in the transverse and vertical dimension. The 15 year old girl in Figs. 21 and 22 displays marked facial asymmetry. This is mirrored in her dentition (Fig. 23), with unilateral posterior crossbite tendencies and a significant deviation if the dental midline.

Fig. 21. A 15 year old girl with marked facial asymmetry.

Fig. 22. A profile view of the patient in Fig 21.

Fig. 23. The dentition of the patient in Figs 21 and 22. Note the midline discrepancy and the unilateral crossbite.

Muscle Tone and Development

Disturbances to the normal growth of muscles of the orofacial region, result in the failure of that region to reach its full growth potential.

Muscle tissue and its influence on the normal growth of the underlying bone can be altered by either the loss of muscle through injury or, the loss of muscle function by injury to the motor nerve of the muscle.

Gross and repeated muscle contractions is associated with *torticollis*. This muscle overactivity, if left unchecked, results in permanent asymmetry from the restriction applied by the contracting muscles, to the underlying developing bone. Early surgical intevention to separate the muscles from bone will prevent the effects of construction (Minamitani *et al.*, 1990).

The loss of muscle tone seen in patients with muscular dystrophy, cerebral palsy and Down's syndrome, affects the vertical jaw growth and displacement, which results in overeruption of posterior teeth and the formation of an anterior open bite (Kiliaridis *et al.*, 1989). The open bite results from the excessive vertical growth of the maxilla and the downward and backward rotation of the mandible. The largely symmetrical decrease in muscle activity is a major contributor to altered facial growth (Gavit *et al.*, 1987, Proffit *et al.*, 1968).

Dental Development

The most common influences tooth development and eruption have on the aetiology of malocclusion post-natally, are to the final positioning of the tooth. The early loss of deciduous teeth can be a significant factor in the development of dental crowding.

The premature loss of a second deciduous molar can result in the mesial movement of the first permanent molar. However as the opposing forces of occlusion are established, this mesial drift effect is minimised (Moss and Picton 1967). Very early loss of these deciduous teeth is treated by the mechanical maintenance of the space to prevent forward movement of the permanent molar and possible impaction of the second premolar.

Fig. 24 shows the outcome of premature extraction of a maxillary deciduous left first molar. Distal drifting of the permanent canine and mesial tipping of the second premolar has resulted in impaction of the underlying first premolar.

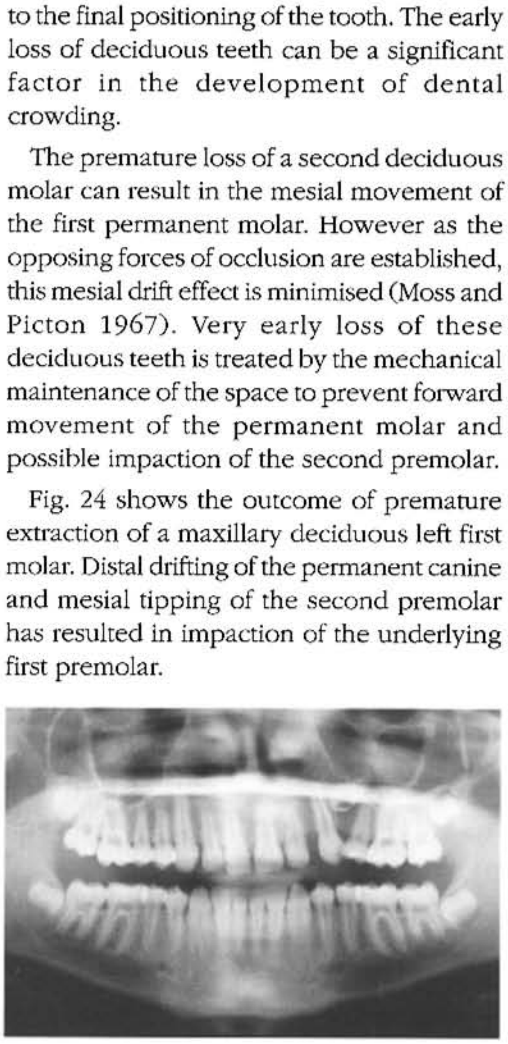

Fig. 24. Premature loss of deciduous tooth has resulted in space loss and impaction of this left maxillary premolar.

The premature loss of more anteriorly placed deciduous teeth can have more generalised effects on the occlusion. The pressure from lips and cheeks, as well as the pull of the gingival fibres, results in the distal

drift of the more anterior teeth (Moss 1980). This results in the loss of arch space and increases crowding of the permanent teeth, as well as a shift of the midline, towards the side where the tooth is missing (Figs. 25, 26 and 27).

Fig. 25. The premature loss of the deciduous right maxillary lateral incisor has resulted in loss of arch length available for the eruption of the permanent lateral tooth.

Fig. 26. Dental crowding (a lateral view of Fig 25) has resulted from early loss of deciduous tooth.

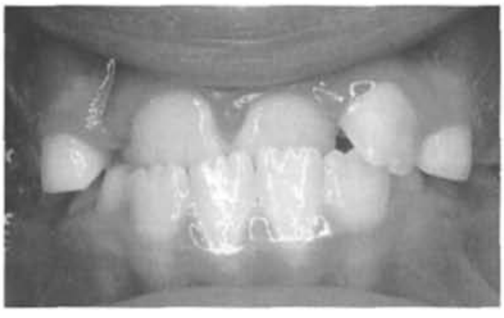

Fig. 27. The maxillary dental midline (a frontal view of Figs 25 and 26) has drifted towards the available space on the right lateral incisor region.

Cross Bites

Posterior and anterior crossbites may develop during dental maturation and eruption through the altered positioning or functional shift of the mandible following premature tooth contacts. These crossbites are usually small in their magnitude, however, if left uncorrected, result in a permanent functional alteration and subsequent malocclusion.

The most common factors associated with the presence of a posterior crossbite are the habitual sucking of thumb and fingers. The narrowing of the upper arch, which accompanies this habit, results in bilateral or unilateral crossbite formation. These crossbites and their associated functional shifts rarely spontaneously correct and depend on maxillary expansion before the functional shift is removed (Fig. 28).

Fig. 28. This 9 year old patient reported a history of thumbsucking. Her occlusion showed posterior crossbites and an anterior open bite.

Anterior edge to edge incisal relationships may result in functional anterior shifting of the mandible, producing an anterior crossbite. Early correction of this shift as the permanent incisors erupt, acts to re-establish the more normal distal position of the mandible, and hence the correction of the anterior crossbite.

Root Resorption

A less common problem seen during dental development is the damage caused to teeth, by the eruption path of adjacent teeth. (Figs. 29) and 30 show the remnants of the lateral incisors that were left without root support after impacted canines caused resorption of the lateral roots. Although uncommon, this example demonstrates the importance of good radiographic surveys prior to the commencement of orthodontic treatment. Similarly, the ectopic eruption of a posterior tooth may also result in an malocclusion. (Fig. 31) shows the left maxillary first molar's ectopic eruption path damaging the adjacent deciduous second molar. Such situations present the orthodontist with the challenges of space loss, dental crowding, tooth impaction and dental trauma, to be corrected, because of the aberrant eruption of a single tooth.

Fig. 29. The radiograph of this 11-year-old showed minimal evidence of maxillary lateral incisor roots. The laterals appeared to be in the path of the impacted canines. Clinically, both laterals displayed noteworthy mobility.

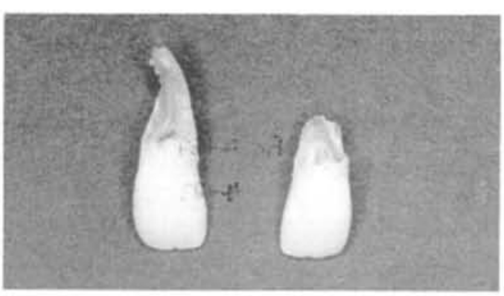

Fig. 30. Following the surgical removal of the maxillary lateral incisor teeth, it can be seen that the canines incisor caused almost complete resorption of the lateral roots.

Fig. 31. The maxillary first molar tooth shows an ectopic eruption path and damage to the adjacent deciduous molar.

Dental Trauma

During all stages of the development of the dentition, primary (deciduous), mixed and permanent, the teeth are susceptible to damage by trauma. The most common injury during the primary dentition phase is intrusion which leads to the possibility of underlying permanent tooth damage through direct disturbance of the developing tooth bud. The stage of development of the forming tooth will determine the injury sustained. If the enamel formation is interrupted, a localised defect will be observed on the crown of the tooth when it erupts. If, however, root formation is taking place, the crown/root orientation of the permanent tooth may be challenged, and a *dilaceration* or crown/root angle disturbance may result. A history of such an injury should have the tooth under careful radiographic review prior to the commencement of any orthodontic treatment as a dilacerated tooth may be difficult, if not impossible, to move.

Trauma during the mixed dentition stage of development may often result in avulsion of an upper incisor. When spaces are created unexpectedly, adjacent teeth will tend to drift and it is important that any such spaces are maintained until a decision is made regarding the treatment of the defect.

Permanent teeth may be displaced and suffer crown and/or root fractures, alveolar bone fractures or lingual or labial displacement (Fig. 32). Teeth with this history should be vitality tested, radiographed and comprehensively clinically examined before a decision to undertake orthodontic treatment is finalised as there is an increased risk of ankylosis or root resorption during or subsequent to orthodontic movement.

Fig. 32. This right maxillary central incisor tooth was moved traumatically to a more labial position. Careful vitality testing and a thorough radiographic examination will be necessary before orthodontic treatment can be commenced.

Occasionally teeth can be damaged latrogenically. Figs. 33 to 37 show the ligation, used to repair a fracture of the mandible, passing through developing teeth. As these teeth were unable to erupt, the surgical removal of the ligating wires proceeded the attempted orthodontic movement of these teeth into the dental arch. Root resorption was one unfortunate sequel in this treatment.

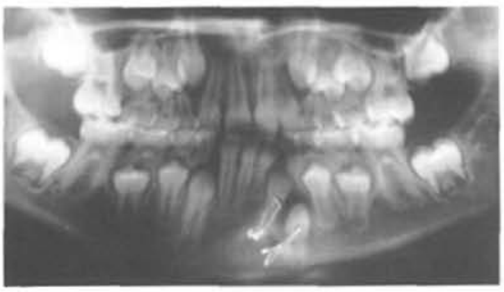

Fig. 33. Ligation of developing left mandibular lateral and canine teeth to mandible, following repair to a childhood mandibular fracture.

Fig. 34. Close view of ligated teeth from Fig 33.

Fig. 35. Following surgery, the wires have been removed, where possible, and cut.

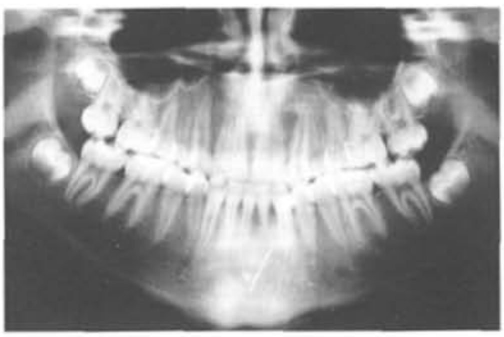

Fig. 36. Tooth position (from Figs. 34 and 35) following orthodontic traction and alignment of unerupted teeth.

Environmental Influences

The effects of the orofacial environment on the development of malocclusion can be seen when forces or pressure, beyond the normal physiological balance are exerted.

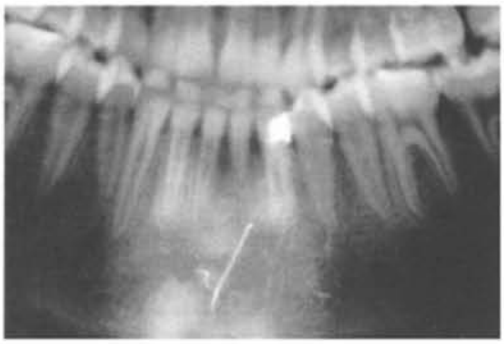

Fig. 37. Closer view of Fig 36 showing remnant wire and root resorption of the lateral incisor.Occasionally teeth can be damaged introgenically. Figs. 33 to 37 show the ligation, used to repair a fracture of the mandible, passing through developing teeth. As these teeth were unable to erupt, the surgical removal of the ligating wires proceeded the attempted orthodontic movement of these teeth into the dental arch. Root resorption was one unfortunate sequel in this treatment.

The theory of equilibrium (Proffit 1993) proposes that light forces of long duration have a greater part to play in alteration of oral tissue equilibrium, than forces with greater magnitude for short periods of time. Although the dentition is subjected to the very heavy forces of mastication, the duration of these forces is momentary. The low grade, constant balance of forces provided by lips, cheeks and tongue have a long standing effect on our occlusion. Light forces of approximately 6 continuous hours duration provide enough force to alter tooth position (Weinstein *et al.*, 1963). Forces of similar magnitude are exerted continuously by the lips, cheeks and tongue and are therefore, believed to be influences in the maintenance of equilibrium of tooth position.

Other physiological forces acting on maintaining tooth position, are the stabilising forces of the gingival fibres and periodontal ligament. Picton and Moss (1973) showed that repeated severing of trans-septal fibres across an extraction region prevented the adjacent teeth drifting together. The pull between teeth, normally balanced, is looking for a new equilibrium when an extraction site exists.

Similarly, the periodontal ligament, which maintains the vertical position of the tooth, responds with eruptive forces when that tooth's occlusal antagonist is removed. The forces and impetus for eruption are poorly understood, however, the excessive eruption of posterior teeth in anterior open bite malocclusion suggests the balance between muscles of mastication and resting tooth contact varies (Proffit *et al.*, 1983).

FUNCTIONAL INFLUENCES

The relatively static and passive nature of environmental and soft tissue influences on malocclusion are reconsidered when many of the same tissues are seen to influence tooth and jaw position in their active or functional roles. This activity is usually associated with a habit or postural alteration and the direction of new pressure or force creates a new bony / tooth response and often, accompanying malocclusion.

Masticatory function

The intermittent nature of the biting force, in line with previously discussed aspects of force magnitude and duration, suggests that tooth biting contact is not a significant aetiological factor in the development of malocclusion. However, the relative undereruption of posterior teeth in deep bite malocclusion and the overeruption of posterior teeth in open bite tendancies, suggests a link between muscle force, tooth eruption potential, facial form and corresponding malocclusion. (Proffit *et al.*, 1983). These are significant differences in tooth contacts during swallowing, chewing and biting, between adult patients with long

faces and adults with normal vertical facial dimensions (Proffit 1983). However, no such correlations show in child and adolescent patients. Biting force does not act as a predictor of malocclusion, rather it can be observed as an effect of the long face, height and low facial and mastication muscle toned individual (Proffit and Field 1983).

Habits

Children who persist in non-nutritive sucking patterns, such as those involving thumbs and digits, are more prone to the development of a malocclusion.

Characteristically these patients present with narrowed maxillary dental arches, proclined and spaced maxillary incisors, retroclined mandibular incisors, anterior open bite or incomplete anterior bite and vertically long faces. These features are in line with the changes to muscle and soft tissue pressure, which are the consequence of the sucking habit. As mentioned previously, those children engaging in long periods of sucking habits (for example, throughout the night) are more likely to create aetiological elements of malocclusion, than those who practise their habit intermittently. Encouragement to curb the habit is important, before the child progresses too far into their mixed dentition development. It is mandatory that the habit ceases before any orthodontic therapy begins.

Proffit (1972) disproved the myth of the 1950's and 60's, that forward positioning of the tongue during swallowing caused anterior open bite malocclusions. His study showed that those who habitually swallowed with their tongues forward, place no more pressure, and perhaps even less, on the anterior teeth when compared with a sample group with 'normal' tongue position.

The tongue position was implicated for its effect on malocclusion, however, in existing anterior open bites, the tongue comes forward to act as a seal for swallowing. This action of the tongue is considered compensatory in this instant and with the transitional phase of physiological tongue thrust during maturation in younger children, are the only times a 'tongue thrust' swallow is observed (Proffit 1993).

Respiration

Respiration may occur through the nose, the mouth or it may be mixed, with a combination of nasal and oral air intake occurring. The posture of the head and neck varies greatly, depending on the normal or habitual breathing pattern for a given individual.

Mouth breathing requires the tilt of the head to be upward with a relative lowering of the mandible and tongue. Because breathing is a 24 hour-a-day 'habit' it holds that alterations in the muscle position and jaw position, over a long period of time, could influence the growth and development pattern of an individual.

Typically, such 'mouth breathing' patients present with long faces, mandibles showing steep mandibular plane angles, increased eruption of the posterior teeth, increased overjet and anterior openbite. Experimentally, however, the relationship between mouth breathing and facial and oral development, has been difficult to prove. Vig *et al.*, (1980) showed that a change in posture will follow when a nasal obstruction is experienced. Normally the nostril and airway size will determine the respiratory volume. Chronic pathological nasal obstruction results in a patient's need to compensate with mouth breathing, at least in part. It has been shown that when such obstructions are removed,

mouth breathing, continues as a component of the normal respiratory mix. Children with chronically obstructed airways (allergic children) have, when compared with a 'normal' group, the increased facial height and overjet and decreased overbite that accompanies the postural changes required for habitual mouthbreathing (Trask *et al.*, 1987).

Although these connections have been made between patients with airway pathology and/or blockage and facial development, there are many, similarly long faced people who show no signs of nasal obstruction. Mouth breathing could be a contributory aetiological factor to malocclusion formation, but the extent is, doubtless, variable amongst individuals.

The continuing search for aetiological influences which directly show a relationship to developing malocclusions, mirrors the orthodontist's desire to plan more effective treatments with more predictable long term outcomes. Unfortunately the words of Edward Angle in 1907 hold as true today as they did then:

"There is much concerning the aetiology of malocclusions that is yet unknown"

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3 The Adolescent Patient

Ockey Brand and Richard Widmer

INTRODUCTION

Successful orthodontic treatment is not possible without paying serious attention to two fundamentally important elements in the orthodontic experience - the biological/dental and the psycho-social. There are sufficient texts on the former, hardly any on the latter and it is this issue with which this chapter is concerned. It deals with the orthodontic experience from the moment the decision has been made to undertake treatment to the moment the last bracket and retainer have been removed. The content of such a discourse would include, therefore, such issues as motivation for treatment, assessment of treatment needs (as much by the patient, as by the parent and/or the dentist) and compliance with, or responsibility for, treatment. Patient attitudes towards dentists and dentistry and the relationship between the patient and the orthodontist are further considerations. Perhaps the most important consideration is the psycho-social development of the growing adolescent. Without this knowledge the chances of achieving the treatment goals are likely to be reduced.

TREATMENT GOALS

Treatment goals are generally directed towards **improved aesthetics and function**. A more encompassing and technical definition is offered by Proffit (1986), who describes treatment goals as "...the creation of the best possible occlusal relationship within the framework of acceptable facial aesthetics and stability of the occlusal result". A variation of this definition, also by Proffit (1986), suggests that treatment goals seek to "...attain and maintain optimum relations in physiologic and aesthetic harmony among facial and cranial structures".

Treatment Needs and Demands

From the point of view of the patient, treatment needs are generally based on three major considerations. These are psycho-social, functional and preventive. Our concern is with psycho-social factors which, generally, have to do with perceptions (of orthodontists, patients and parents) of unattractiveness and disfigurement as a social handicap and the extent to which that could significantly affect future life issues such as employability and

marriage opportunities (Morris *et al.*, 1977; Cons *et al.*, 1983). It is one of the major factors that brings patients to the door of the orthodontist. Approximately 35% of adolescents are perceived by parents to need treatment for psycho-social reasons and another 20% are referred by dentists (Kelly and Harvey, 1977).

Children, Adolescents and Adults

Earlier research on the child orthodontic patient (Storey, 1966) suggests that the underlying motivation to visit the orthodontist is often a reflection of parental anxiety and concern that their child will conform to both their own and society's idea of beauty and facial attractiveness. The point to be made is that children are taken to the orthodontist with little choice in the matter.

Adults, on the other hand, are generally self-motivated and are usually conscientious about following treatment regimens (McKiernan *et al.*, 1992). Other writers, such as Kiyak *et al.*, (1982) have observed that those adults who do seek orthodontic treatment tend to reflect positive self-images. Available evidence, albeit limited, suggests that these patients are also characterised as having well-developed egos, or as possessing ego-strength (Proffit, 1986). The implication is, of course, that taking responsibility for their role in treatment is unlikely to be an obstacle.

There is less certainty about adolescent patients. Lawrence *et al.*, (1990) have shown that the cooperation during treatment is variable and unpredictable. A study by Kegeles and Lund (1984) on adolescent health beliefs indicated that there was no relationship between these beliefs and preventive dental action. As a consequence, motivation for treatment could be ambivalent and there may be an unwillingness to meet their obligations, which are:

1. The initiation and maintenance of consistent preventive oral health behaviours - brushing, flossing, disclosing, regular examination.
2. Consistent wearing of orthodontic appliances.
3. Dietary control - reduction and if possible, elimination of cariogenic food and drink.
4. Care to avoid breakages of appliances.

It is precisely in this area, where successful treatment depends on patient compliance, that conflict between orthodontist and patient often arises. Some feel (Dobyns, 1978; Ross 1991) that the assumptions that underlie the notion of compliance are questionable and would, therefore, be worthy of exploration and discussion.

COMPLIANCE-PROFESSIONAL AUTHORITY (SOCIAL CONTROL) OR MUTUAL PARTICIPATION AND RESPONSIBILITY

The concept of compliance is generally taken to mean the extent to which a person's behaviour (in terms of taking medication, following diets, executing lifestyle changes, or taking preventive action) coincides with medical or health advice (Haynes 1979). Non-compliance is, therefore, a lack of adherence even when the correct advice, instruction or regimen are known (Davis 1968). From the point of view of the doctor's dominance, with its aura of detachment and authoritative technical competence, the role of the patient can be seen as essentially accommodative and cooperative to the doctor's task (Davis, 1976).

A confirmatory statement is made by Conrad (1985) who says that the concept of compliance suggests a "...medically-centred orientation which is based on the assumption that the doctor gives the orders; patients are

expected to comply". In the field of dentistry, Linn (1967) makes a telling point. In a study where the surgery behaviour of 27 dentists was observed, he says that "...the governing attribute (needed for relations to continue) of the role of the patient was conformity and that of the dentist was the authority to direct".

This pattern of doctor/patient interaction is assumed by many health-care practitioners to be the base upon which "good" medical and dental practice rests. Professional authority is hardly questioned when it is predicated upon and legitimised by the knowledge, skills and expertise professionals are assumed to possess. Such thinking rests on extremely plausible and widely acknowledged premises and would generally be taken for granted if it were not so problematic. If such a relationship were thought to be effective - in other words, if most patients did indeed take their doctors/dentists seriously, act on their advice and follow their instructions there would be no need to question it. But reality is of a different order and the truth is that they do not.

The Nature of the Problem

Many studies (Davis, 1968; Hulka *et al.*, 1975; Hayes-Bartista, 1976; Christenson, 1978; and Ley, 1981) have shown that at least one-third of patients with a variety of conditions are non-compliant with their medication regimens. In some cases this rate has risen to a level of 50% (Sackett and Snow, 1979). The rate of non-compliance with the medication intake of chronic pain patients has been shown to vary from 19% to 72% (Hayes-Bartista, 1976). These examples of studies on non-compliance, of which there are many, indicate the seriousness of the issue and highlights its intractable nature in health care (Kotarba and Seidel, 1984).

Reasons for low compliance rates are varied and many. They include such behaviours as poor patient recall, lying about compliance, challenging the professional's authority, (DiMatteo and DiNicola, 1982), **poor doctor/patient interaction** (Garrity 1981) and **dissatisfaction with ineffective doctor communication** (Locker and Dunt, 1987; Ley, 1981).

The belief that an authority-based approach to prescriptive treatment would automatically be followed by patient compliance has now been seriously called into question. What may be necessary, then, is, firstly, to discover ways in which specific **communication skills could be improved** and, secondly, to seriously consider modifying or even radically **changing the traditional authority-based doctor/patient relationship** and replacing it with one that is more democratic.

But first a look at the old and why it needs changing!

Compliance - the concept and its meaning

Ross (1991) argues that "...the word compliance carries with it implicit value judgements. The compliant patient is seen to be a 'deserving' and passive recipient of health care, in contrast to the 'unreliable' and 'blameworthy' non-compliant patient. Thus, responsibility for non-compliance is seen to lie with the patient and, by implication, blame or merely critical attention is withdrawn from the health care system". In its more extreme forms, non-compliance - particularly when malingering is suspected - has been described as "socially deviant and morally stigmatised" (Kotarba and Seidel, 1984). Populations of chronic pain patients have sometimes been described in these terms.

It seems that the use of the term compliance is in need of revision, not only because of its pejorative overtones but also because its definition is one-sided.

Towards a new concept of compliance

In view of the negative connotations of the word compliance, the term adherence has come to be used as an alternative (Blackwell, 1976). This notion, while less pejorative than the term non-compliance, still does not take into account the wider implications of the term and it is Dobyns (1978) and Ross (1991) who propose the idea of responsibility instead. They clearly suggest that, if treatment is to be successful, improved communication is essential and that **both patient and professional need to be held accountable** and take responsibility for treatment.

This notion is supported by extensive research evidence. Woolley *et al.*, (1978) have shown how patient satisfaction with care is related to effective communication. Other workers (Davis, 1968; Bertakis, 1975; Garrity, 1981; West, 1981; and Ley, 1988) have demonstrated that a better understanding of instructions has been associated with effective communication, and that improved drug compliance and effective communication are related. The orderly and methodical presentation of instructions (Van Zyl and Brand, 1989) are likely to enhance treatment outcomes.

It is clearly evident that the conjoint responsibility of orthodontist and patient, with clearly defined roles for each, are necessary. How this may be achieved will be taken up later, but, from the patient's point of view, let it be said at this stage that bilateral consultation in the planning and decision-making process is likely to enhance acceptance of the patient role and therefore responsibility for successful treatment. This, in turn, could well reduce resistance to demands for compliance as well as the demands themselves. Furthermore, if orthodontists are sensitive to the social needs of these patients the chances of them accepting responsibility and **adopting the patient role by choice, rather than by decree** are likely to be enhanced.

Discovering the Need for Treatment

Before addressing the issue of the adolescent's social needs, it would seem appropriate to begin with the initial discovery of the need for treatment.

This is often noticed, usually by the parent, well before adolescence. Even at age 7 or 8, during eruption and growth periods, teeth can be seen crowding, protruding or splayed. The child is usually taken to the general dentist whose opinion is sought and who then usually refers to the orthodontist. What is clear is that there is an awareness that a problem exists.

Some knowledge of the cultural values, beliefs and attitudes of patients and their families towards health and patterns of service utilisation might also be helpful in assessing the likelihood of the patient accepting responsibility for their part in the treatment program. This information could be acquired during the interview and may be elicited with questions that probe the number of dental visits per year and reasons for such visits. Beliefs about the value of home dental care and preventive behaviour, as well as dietary patterns and expectations they have of orthodontic treatment, provide additional indications on what future patient action is likely to be.

PSYCHO-SOCIAL DEVELOPMENT AND THE LIFE TASKS OF THE ADOLESCENT

Physical

Growth and development during this period is rapid and is manifested by highly visible changes. There are increases in height and weight and maturation of primary and

secondary sexual characteristics. There is often some apprehension associated with these changes, for they bring with them the need to revise one's body image and pull it into line with the fashions of the day and the prevailing culture. There are strong and often fearful implications which this has for one's appearance, personal identity and attractiveness to others.

Mental/Intellectual

Intelligence is an important aspect of personality for it buttresses the self-concept and confirms self-esteem and self-worth. The implications are that it sustains the notion of "I am clever, I can understand and cope with my environment and the demands it places on me". Such self-statements have implications for confidence, self-reliance and dependability. If absent, there may be a lack of confidence in oneself and doubt about how well demands can be understood and managed.

Social Development

Need for independence

This is often a difficult issue because it can occur only as a process of liberation or emancipation from the family. It is usually associated with strong feelings of ambivalence and anxiety and is characterised by the need for independence on the one hand and a state of social immaturity, usually defined by parents, on the other.

Major areas of conflict are usually around issues of rights and priviliges and the questioning of parental rules. Adolescent children often respond with plausible alternatives which can, and often do, result in less obedience and more resistance. As an orthodontist, one needs to be particularly aware of this process - for, as Hartup (1983) suggests, **if disagreements can be consistently met with open discussion, self-reliance and a sense of social responsibility are often a more than satisfactory consequence. The lesson is, of course, as much for orthodontists as it is for parents.**

At a more unconscious level, reaching for independence also means "rejecting" parents and "replacing" them as primary relationship people with peers of the same and opposite gender. Relationships with parents are later re-defined and become adult-to-adult, which replaces the earlier child-to-adult relationship. The move to independence brings with it the need for:

Intimacy and intimate relationships

These pave the way for future adult relationships and the socially responsible roles of marriage and parenthood. Adolescence is a time for relationship testing. It brings with it uncertainty and anxiety, particularly with regard to trusting others and being trusted, sexuality and sexual practices and the consideration of people as possible future life partners. At a deeper level, it is almost a universal need for closeness and intimacy but the inexperience and lack of social skills often make the development of intimate relationships difficult to acquire and manage.

Social identity

Basically, the quest for a personal and social identity addresses the question of "Who am I?" Accordingly, **the orthodontist is involved in this issue, not only as a quest for personal identity but also as a motivating factor for seeking orthodontic treatment**.

Career choice

This is a major life task, often associated with ambivalence and uncertainty, particularly when an early choice cannot be made or is difficult to make. Confusion and

uncertainty increases as the time for a serious decision approaches. Evidence suggests that late deciders may become disenchanted and disillusioned later in the workplace. Fear of wrong choice is present because there are in fact so many choices, coupled with the difficulty of entry into favoured occupations.

Emotional Development

Difficulty and confusion confounds ways on how best to deal with issues that always have an emotional content - which is just about everything. This includes learning about, getting in touch with and managing feelings like anger, guilt, aggression, and sadness. **Acquiring emotional maturity is perhaps the most difficult aspect of personal and social development, mainly because they are neglected in favour of intellectual and physical development.** Emotional considerations, furthermore, lag far behind physical and intellectual ones in terms of the total development of the individual.

Knowledge of the typical ways in which adolescents respond emotionally to obstacles that block personal gratification is invaluable.

Another dimension to this problem is the wider issue of stress and the way it is perceived and managed (Charlesworth and Nathan, 1987). Knowing how the patient perceives and manages stress offers the possibility of acquiring important information and insights, perhaps, into the nature of the patient's problems but, more significantly, about the patient and the way they should be dealt with.

NEW APPROACHES TO THE ADOLESCENT ORTHODONTIC PATIENT

The following suggestions, with regard to an approach to the adolescent patient, are made with the knowledge that they are open to change in ways that may be better known by orthodontists than by psychologists. They do, however, provide a useful framework within which some strategies could be developed.

During examination and diagnostic interviewing what may be included are simple questions probing some of the more relevant psycho-social issues. This questioning could take the form of a semi-structured interview or it might be open-ended and totally unstructured depending on the orthodontist's preferences and interviewing style. Perhaps the point to be made is that there are no hard and fast rules about interviewing and you might like to choose the method with which you feel most comfortable. It might also be useful to record and transcribe the interview.

To begin with, it might be appropriate for the orthodontist to open the discussion with a clarification of the roles that will define their relationship and that each will play in the forthcoming treatment.

ROLES OF PATIENTS AND ORTHODONTISTS

The Patient's Role

According to Lahti *et al.*, (1992), the patient's role can be defined relatively simply. They suggest that it needs to be

1. Motivated and compliant, which refers to:
   a. an understanding of the necessity for treatment;
   b. motivation to take care of his/her teeth;
   c. following instructions;
   d. trusting the treatment given by the orthodontist; and
2. Punctual and active. This refers to the expectation the orthodontist may have of the patient to come in on time, pay bills on time and accept the treatment plan.

These notions are, of course, simplistic but nevertheless outline in quite specific terms what is expected of the patient. What is overlooked, however, is the complex set of factors that underlie this process, the difficulties, for example, in accessing potential resistance and the sources of variable and unpredictable behaviour. Or the opposite - generating a set of criteria that can be trusted to identify behaviour which can reliably be labelled responsible or dependable. The fact of the present discourse testifies to the complexity of an uncertain process and implies that a commitment to open discussion has the best chance of moving towards solving this dilemma. Finding factors that predict "compliant" behaviour, however, remains a problem, although considerable work in this area has been undertaken.

Predicting Patient Behaviour

Albino (1981) and Lawrence *et al.*, (1990) have investigated the role of personality factors as predictors of "responsible" patient behaviour. Their findings suggest that these variables cannot be relied upon with any real confidence. El-Mangoury (1981) hypothesised that orthodontic "compliance" was predictable on the basis of psychological testing and as early as 1968, Kreit *et al.*, suggested that "the poor relationship between the parent and the patient" was the most salient factor in those patients being identified as non-cooperative. However, a study by Nanda and Kierl (1992) found the factor of major importance was the orthodontic/patient relationship.

This is a compelling finding but there is, unfortunately, very little indication of what the nature of such a relationship is or needs to be. One might plausibly argue, then, that the quality of the orthodontist/patient relationship, if it is to function effectively, would be determined in large measure by the need for orthodontists to have, or acquire, specific competencies and functions. In fact, in the concluding statement of their paper, Nanda and Kierl (1992) suggest that "...we, as doctors, may tend to blame the patients quickly, rather than ourselves if the course of treatment is not going as desired. If we were to look at ways to improve communication with our patients, we might be able to 'salvage' a potentially uncooperative patient".

In dealing with the question of the orhodontist's role, the issue of competencies and functions is addressed.

The Orthodontist's Role

1. **Professional and technical competence** - this of course is a minimum requirement.
2. **Being the "good" communicator** - this involves a number of competencies:
   a. rests on the notion of communicator credibility, depends on the expression of balanced views, demonstrates a lack of ulterior motives and reflects sincerity and trustworthiness. Professional power that rests on the basis of professional expertise which is recognised as legitimate and authoritative but not coercive;
   b. informative - provides comprehensive information, instructs and explains well;
   c. carries out target analysis - establishes criteria such as age, gender, cultural background etc. that enables the orthodontist to pitch the message appropriately in terms of content and mode of presentation (Freedman *et al.*, 1978; van Zyl and Brand, 1987 & 1989; Lahti *et al.*, 1992).

Part of being the "good" communicator includes a proficiency in health education - specifically (Fisher *et al.*, 1986), if not by the orthodontist, then at least by the dental auxiliary.

3. **Supportive** - encourages and takes patient seriously, acknowledges the presence of uncertainty and anxiety and helps to remove these negative emotional states (Corah *et al.*, 1988).
4. **Facilitates and enables** moves by the patient towards responsibility rather than by making demands on the basis of professional authority. This suggests, furthermore, identifying and exploring problem areas that may interfere with acceptance of the patient role, acknowledging feelings, particularly negative ones that might generate resistance and, finally, looking for possible solutions. The approach is **essentially patient-centred** (Conrad, 1985), for it not only sees the problem from the patient's point of view but encourages the patient to consider potential solutions and accept responsibility for their implementation.
5. **Flexibility** - allows for the exploration of alternative options - where compromises on the wearing of head gear, for example, might be sought so that there is minimal conflict with the patient's activities (school, sporting), or possible feelings of embarrassment on the one hand and minimal disruption of the treatment program on the other.
6. **Non-punitive** - will not ridicule or criticise the patient if there are lapses in maintaining oral health standards for example, or 'dietary deviance' but rather engaging in discussion about the possible reasons for such a lapse and using this encounter as the point of departure for re-evaluation and new learning. This approach is supported by Tedesco *et al.*, (1991), who suggest that "...it would be counterproductive to consider performance lapses as an end point of failure." George *et al.*, (1988) also make confirmatory statements in this regard and suggest how 'failure' provides new information for future learning. They state that "...in learning any new behaviour, lapses inform the person about any unforseen pitfalls, convey corrective feedback and impart guidance about how one might avoid future mistakes."

The point is emphasised that the above 'management styles', are believed by many to be beyond the scope of 'ordinary people'. This is not the case, for effective communication skills can be learned and are well within the scope of most people. One might also add that the possession of these skills is a must for all health care professionals (Dickson *et al.*, 1989).

Additional Factors

There are two additional factors that might be worth considering and using. The first is to develop **good listening skills**. This statement is somewhat trite but to listen well has important advantages for it helps to acquire accurate and comprehensive information about what the speaker is communicating but more importantly, perhaps, about the speaker (patient). Good or empathic listening, according to Steward (1977), is an indispensable and basic communication skill.

Secondly, **treating the patient in an adult manner** assumes that you acknowledge maturity, accord responsibility, invoke trustworthiness, and implicitly respect the patient. It assumes, too, that if you are

seen to trust others they are likely to behave in a trustworthy manner. It carries with it an element of risk but better the risk, perhaps, than imposed authority against which there could well be resistance.

Conducting the Interview

What follows provides an example of the social or personal interview. Its purpose is to acquire as much information as possible about the patient's social reality and explores the kinds of questions that are likely to probe the psycho-social issues referred to earlier. These questions will then be analysed in terms of their informational value, meaning and possible future lines of questioning.

It goes without saying that the interview should be conducted in as sensitive a manner as possible and that questions should be non-threatening and neutral. A useful point of departure could be from within the patient's role. Reference can once more be made to the nature of the orthodontic problem, the treatment that has been shown to be necessary and the oral health, dietary and 'appliance care' the patient has been requested to carry out. One assumes that this information has already been provided, so, an opening question might be,

"Is there anything that you do, like playing sport, or taking part in school plays, for example, that might be an obstacle to your wearing bands, elastics and headgear and would, therefore, be likely to interfere with the treatment?"

If yes, then, "What are those things?"

What these questions do is to open opportunities for the acquisition of information about the patient's interests and activities and the nature of problems that may act as barriers to 'head gear wearing', for example. They also allow for the exploration of options that would take the patient's need into account without compromising the treatment requirements too much.

Let us assume that the patient responds by saying that one of the barriers to wearing head gear at school is that friends make fun of him/her.

A follow-up question might then be "...How do you respond to their teasing?"

What may emerge from a discussion on this topic could be insights into the levels of emotional maturity patients may display and the degree to which they regard issues as trivial or serious. An emotionally intense response, for example, to what may be regarded as a relatively innocuous or trivial issue (by normative standards), might prompt questions that probe areas, that to the patient may be seen as stressful. Before any further questioning takes place a comment that acknowledges the patient's feelings would be totally appropriate. This is an important first step in establishing rapport. Follow-up questions could then be,

"Do you get upset easily, do you get upset often?" or "what else upsets you?" or "when you are upset how badly do you feel and how long does it last?"

These questions could open up specific aspects of the patient's stress 'profile', for they point to such issues as the frequency, intensity, duration and range of responses to 'stress' as well as to coping styles. Such information could provide important clues to the 'emotional vulnerability' (or lack of it) of the patient and its implication as a potential emotional barrier to treatment.

The question of emotional difficulties is not to be underestimated, for Wright and Jacobs (1990) have shown in a series of case studies the extent to which psycho-social problems are evident during orthodontic treatment. If the issue is serious it may then be necessary

to refer the patient to a psychologist or a social worker. The point is made to indicate that, to a greater or lesser extent, emotional problems often present themselves and while orthodontists are not called upon to be psychologists they need to be aware that such problems can and do occur and need to be appropriately addressed.

The issue could be further pursued with a question that may throw light on the patient's relationship with his/her family, for it would not be unreasonable to enquire whether, in the event of being upset by friends, they would bring the problem home to parents.

"Do you share these kinds of events with your parents?", might be an appropriate question to ask. If the answer is in the affirmative, this might immediately be followed by,

"How do they respond to you when you get upset?"

Once again, such a question raises the possibility of acquiring new knowledge in an area where it might be possible to discern the nature of the relationship patients may have with their families. Are they helpful and supportive or do they tend to be dismissive and distant? Such information could help the orthodontist to establish whether the family could be relied upon to be supportive if there are lapses by the patient during treatment.

To return to the question of friends. It might be useful to enquire whether the patient has friends who may also be wearing orthodontic appliances. If they do, the problem of uniqueness and high visibility and the potential for ridicule could be considerably minimised. In some schools it is almost unfashionable not to be wearing orthodontic bands and, with the move away from curative dentistry towards aesthetic and corrective dentistry, the number of orthodontic patients is likely to increase. Being singled out for ridicule because one wears orthodontic appliances seems to have become, in some circumstances at least, less likely.

Information on personal and social identity is important to acquire and a question that could plausibly be asked might be,

"Is there anything about your appearance that you don't like?"

This question touches on some significant developmental and motivational issues, for it asks, **"can the way you look physically be integrated with who you are, your ego-identity in other words, and rest there comfortably?"**

If not, it is little wonder, then, that the orthodontist is called upon to perform the miracle of physical and psychological transfiguration which provides, no doubt, the *raison d'etre* for the visit in the first place.

The quest for ego-identity during adolescence is described by Eriksen (1968) as one of the more important and difficult life tasks the adolescent is called upon to negotiate. Its purpose is to acquire a stable, socially acceptable and personally satisfying identity in the face of perpetual conflict. Eriksen describes it in the following manner. During growth, what the adolescent gradually acquires is a personal value system which has as its touchstone the notion of fidelity - faithfulness to oneself, faith in oneself, in others, to what one believes in and to what one wants to do. The problem, of course, is to integrate all the diverse and often contradictory aspects of ourselves - our experiences, beliefs, values, abilities, failings, the love of others - into one meaningful whole that says, "This is me, this is who I am!" and "If I am not sure that the way I look can be integrated with who I am or want to be, then I will need your help Doctor!"

"Certainly" could be the orthodontist's rejoinder, "I need your help too - we need to help each other!"

"How?"

"Well, let's discuss how."

And so, other options open up and many doors wait to be unlocked.

Other kinds of questions that could be put to the patient might include,

"What sorts of things do you think people like about you?"

This is a useful question to ask for it provides balance and offers opportunities for positive and confirmatory statements to be made about the patient. **Praise and approval, appropriately and consistently given, is an effective social reward and can be effective in sustaining the patient role.**

Finally, a few words about relapse prevention. It has already been suggested that a relapse maybe viewed as a "stumble, rather than a fall and as a correctable mistake". Such an experience may be viewed as a point of departure for new learning. Translated into an interview procedure, appropriate questions might be,

"What brought on the relapse?" or "What interferes or has interfered with your daily oral hygiene routine?" and "How can we find a way, or ways, to overcome this problem?"

These questions, particularly when asked to acquire information rather than to criticise, open up possibilities for identifying the nature of interferences but, importantly offer opportunities to explore strategies for future prevention.

The above section should not be regarded as the only way in which an interview could be conducted. It merely serves as an example of how questions could be asked or phrased, what their nature and sequence could be and how the well-placed question may be helpful in identifying problem areas and suggesting possible solutions.

Communication styles vary and the same end point may be arrived at by many different routes. It is not necessary to be a psychologist to become the "good" communicator. We are all capable of learning these skills. What may be more difficult is to acknowledge that it is, in fact, possible.

CONCLUDING SUMMARY

This section has set out to address the issues surrounding what I would now like to describe as "patient responsibility", rather than compliance, in relation to orthodontic treatment.

The underlying assumption asserts that knowledge of the social context of the patient and the psychological factors associated with treatment is likely to minimise the difficulties in achieving treatment goals.

The issue of treatment need and demands is addressed with special reference to underlying motivation in relation to child, adult and adolescent patients. The differences in self and other motivation in adults and children is noted, while the uncertainty and unpredictability of the adolescent patient is highlighted.

This has implications for a new approach - re-conceptualising the notion of compliance. The need to do so is based on the rationale that its present meaning reflects the ease with which people can use the term to blame and label others in terms of their responses to professional authority. The term patient "responsibility" is suggested instead.

The life tasks of the adolescent are spelled out in some detail. Familiarity with this information is indispensable for the structuring of a social platform which provides the base upon which a relationship can be built. This is no ordinary relationship, for it is long-term and beset with many unseen hazards and

potential pitfalls. It needs to be special in the sense that certain features need to be put in place that will ensure its durability and effectiveness.

Discussing and defining orthodontist and patient roles has the advantage of outlining clearly what each is expected to do and what each expects from the other. Suggestions are made about the specific features of these roles, such as the manner in which they would need to relate to one another and how they should ideally operate, with the emphasis on skilled communication, open discussion and the management of relapses. The responsibility is more the orthodontist's than it is the patient's when it comes to defining the boundaries of their respective roles. The patient is called upon to participate.

Finally, an illustrative interview with interpretations is presented. It focuses on a particular interviewing style, the manner in which questions are asked and phrased and how one question leads to the next. Its purpose is to seek specific psycho-social information, develop and consolidate the relationship and integrate this knowledge with the call for patient commitment to the orthodontic experience.

Note: Apart from individual references quoted in the text, information on the "Life tasks and psycho-social development" section may be found in "Introduction to Psychlolgy" (1986) by Morgan, King, Weisz and Schopler. McGraw Hill, Chapter 12 464-479 and "Human Behaviour" by Nash, Stoch and Harper (1984), David Phillip - Cape Town and Johannesburg. Chapter 10 pp. 87-100.

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4 Orthodontic Photography

Simon R Freezer & John P Fricker

INTRODUCTION

The statement "A picture paints a thousand words" is as true in orthodontics as it is in all other facets of life. Its importance in daily orthodontic practice cannot be overstated. However, as recently as 1991 only 50% of the orthodontic programs in the United States had a course in clinical photography (Sinclair and Rudolf, 1991), a figure that was relatively unchanged from the 43% noted in 1983. This was in spite of the increased need for good records to meet orthodontic certification and the need for adequate documentation for risk management. For patient, parent and practitioner education, as well as for treatment evaluation, pretreatment, progress and end of treatment photographs all have their place in orthodontics. With the lengthy time frame involved, patients and operators alike have considerable difficulty recalling the type and extent of initial intra-oral and extra-oral problems.

When considering the costs involved, the simplicity of taking standardised photographs and the ease with which they can be stored, routine photographs should be taken for all patients. However, despite this, there is a lack of available literature detailing the principles of orthodontic photography, the types of equipment available and the clinical procedures necessary for standardised quality images.

Some pertinent theoretical aspects of photography are covered in this chapter. However, those seeking more detailed explanation of the scientific principles involved are referred to one of the numerous general photographic texts.

Similarly, it is not the purpose of this chapter to describe any particular proprietary system in detail. With continual advancements in cameras, flash units and lenses any particular system will eventually become outdated and unavailable. Rather the intention is to document the principles behind dental photography and address considerations that are relevant to both traditional film based and digital systems. As such, practitioners, armed with the appropriate information, can select a camera system suitable to their needs. A clinical regime can then be implemented such that quality clinical photographs can be consistently produced.

However, it must also be remembered that all photographs remain a two dimensional representation of three-dimensional problems. Adjuncts such as study models are essential pre-treatment records to help evaluate the progress of treatment during orthodontics.

General Photographic Principles

Photography begins and ends with light. As light enters a camera and is focused into an image, the chemical changes occur on the film's surface. The film is treated with certain chemicals to produce an image or negative (developing). By transferring the image from the film to a sheet of special paper a positive print is made.

There are five steps in the photographic process. These are capturing light rays; focusing the image; exposing the film; developing the film and making a print.

Capturing Light Rays

A camera is basically a box with a small aperture (opening) at one end and film at the other end. The inside of a camera is completely dark so that rays of light reach the film only through the aperture. A device called a shutter opens to take a picture. The shutter remains closed at all other times in order to keep light away from the film.

The lens system concentrates incoming rays of light on the film and gathers enough light to expose the film in only a fraction of a second. Without a lens, the exposure might have to last as long as several minutes.

Light from an object passes through the aperture and forms an image of the object on the film. Light from the top of the object pass through the lens aperture and strike the lower part of the film. Light from the bottom of the object form the upper part of the image. Thus, the image on the film is upside down.

Focusing the Image

As the light rays pass through the aperture into the camera, the lens bends them so that they form a sharp image. The sharpness of the image depends on the distance between the object and the lens, and between the lens and the film.

Exposing the Film

Black and white film is a thin sheet of paper or plastic with a coating called an emulsion. The emulsion consists of tiny grains of silver salts held together by a jelly-like substance. Silver salts are highly sensitive to light and undergo chemical changes when exposed to it. The degree of change in the salts depends on the amount of light that reaches them.

Light coloured objects reflect more light, than dark colours. The silver salts on the film react differently to different colours. Light from a white or yellow object will change the salts greatly while light from grey or tan objects will change them only slightly. The chemical changes in the silver salts produce a latent image on the film which contains all the details that will appear in the photograph.

The amount of exposure that film receives is determined by both the intensity of the light that strikes it, a function of both the aperture setting of the lens and the subject's brightness and the duration of the exposure, a variable controlled by the camera's shutter. This relationship is expressed by the equation:

- Exposure = Light Intensity x Time

Thus the lens, camera shutter and the camera flash can be used in combination to manipulate the final exposure. With flash photography, the flash unit needs to be synchronised to a fully open shutter so the shutter speed can only be regulated to a limited extent. When faster shutter speeds are used, usually faster than 1/60 or 1/125 of a second, the shutter will not be fully open when the flash fires and only part of the image will be properly exposed.

If the camera shutter is open for too long, the flash is too bright or the aperture too wide open then the image will be over-exposed. Over-exposed images appear white and

washed-out; they lack contrast and detail. By contrast, under-exposed images appear dark and any detail is hard to see (*Fig. 1A, B & C*).

The amount of exposure a film requires for proper exposure varies with the crystalline structure of the film and is designated by its film speed. Faster film has larger photosensitive crystals and requires less exposure than slower film (Schaefer 1995).

A

B

C

Fig. 1. A - Correct exposure.
B - Under exposed.
C - Over exposed.

Developing the film

After the film has been exposed, it can be removed from the camera. Then be kept away from light in a darkroom or a photographic laboratory. It is treated with chemical developers that convert the silver salts on the emulsion into metallic silver. The image on the film then becomes visible.

During development, the silver salts that received much light form a thick deposit of silver and appear dark on the film. The salts that received little or no light form a thin metallic layer or no layer at all. They appear light or clear on the film. Thus, the light colours and dark colours of the subjects photographed are reversed on the film. The developed film is called a negative. Before further processing, negatives are treated with a chemical solution that makes the image on the film permanent or fixed.

Making a Print

Making a print is similar to exposing and developing film. Like film, printing paper is coated with a light-sensitive emulsion. Light passes through the negative and exposes the paper, forming a latent image. After development and chemical treatment, the image on the printing paper is visible and permanent.

Choice of film

Films differ in many ways. They can be colour or black and white. Alternatively, film can be transparency film for colour slides, or colour reversal film, which is used for colour prints. Black and white film is generally not used for orthodontic photography and it is a matter of personal preference as to whether colour slides or colour print film is used.

The advantages of slide film include ease of storage, suitability for lecture presentation and the ease with which prints can be made from slides if required. The disadvantages of slide film include the need to be projected to be seen clearly the reduced latitude that exists to compensate for variations in exposure, film processing and non-standard clinical technique.

It should also be noted that there are methods of readily making both slides from prints and vice versa. Prints can be photographed with slide film. Conversely slides can either be replicated to negative film, which in turn is reprinted, or printed directly onto colour positive paper such as Cibachrome or Ilfochrome paper.

Computer technology can also be utilised. Slides can be scanned and printed with a colour printer. Prints can also be scanned and slides then made by sending the digital image file to a computer slide bureau. However, regardless of the technology employed, some loss of image quality can always be anticipated when slides and prints are made from each other.

Film also varies in its sensitivity to light. The principal systems for measuring film speed are the DIN system, used chiefly in Western Europe, and the international ISO system. The higher the ISO rating the faster, or more sensitive, the film. Film with and ISO rating of 400 is twice as sensitive as ISO 200 film. The trade off for faster film speeds is larger silver halide crystals which equates to an increased graininess of the final image. Film contrast also usually increases with an increase in film speed. Different manufacturers tend to produce films with different grain size for a given film speed as well as a different colour cast to the film. Generally films should be selected with the finest grain size possible and a consistent colour cast that can be adjusted with colour correction filters.

Principles of Close-up Photography

Close-up photography has more stringent demands than some other fields of photography and requires appropriate illumination of the subject, adequate magnification, sufficient depth of field and minimal image distortion. Clinically, a flash unit is used to achieve this illumination. Image magnification, depth of field and image distortions are functions of the camera lens system.

To achieve these goals consistently, both appropriate equipment and a standardised technique are required. This is particularly the case in dentistry because most often neither the patient or camera are fixed and a comparatively long depth of field is also required. Additionally, if a reasonable number of photographs are likely to be taken, the system must be fail safe, economical and easy to operate.

Appropriate subject illumination

Natural light and artificial light have certain characteristics that greatly affect the quality of photographs. These characteristics include direction, intensity and colour.

Direction

The direction from which light strikes a subject can be from the front, the side, the back or the top. Light may also strike a subject from several directions at once. The direction of light greatly affects how the subject looks in the picture.

Front lighting comes from a source near or behind the camera. This type of lighting shows surface details clearly. Although avoided for professional portraits of people, because the light casts harsh shadows under their features, using the camera's flash unit provides a convenient and consistent method of illumination for extra-oral photographs.

Side lighting shines on one side of the subject. Shadows fall on the side opposite the source of the light. Flash fill-in can be used to lighten these shadowed areas. Side lighting does not show surface detail as clearly as front lighting does, but it creates a strong impression of depth and shape.

Backlighting tends to create outlines and silhouettes. It is not really suitable for clinical photography.

Top lighting comes from a source directly above the subject and casts shadows under the patient's chin and other facial features. It is generally used in situations where other types of lighting would cause a glare or reflection in a picture.

Intensity

Intensity is the quantity or brightness of light. Photographers measure the intensity of light to determine the lighting ratio of a scene. The lighting ratio is the difference in intensity between the areas that receive the most light and those that receive the least. On a sunny day or in a room with bright lights, the lighting ratio is likely to be high. On an overcast day or in dim indoor light, the ratio is lowered which, with less severe shadowing, makes portraits more flattering and more natural.

Colour

The colour of light varies according to its source, though most of these variations are invisible to the human eye. For example, ordinary light bulbs produce reddish light. Fluorescent light is basically blue-green. The colour of sunlight changes during the day. It tends to be blue in the morning, white at about noon and pink just before sunset.

The colour of light is described in terms of colour temperature. Photographic daylight has a colour temperature of 5,500K. Colour temperatures above this equate to a bluish hue whilst images with a colour temperature below 5,500K have a yellow cast. Light balancing filters that decrease the colour temperature of the original source add a yellowish tinge to, or remove a bluish tinge from an image. Filters such as 81A, 81B, 81C, 81EF, 85A, 85B and 86 add increasing amounts of yellow to an image. Yellowness can be removed or blueness increased by increasing the colour temperature of an image by using filters numbered 82A, 82B, 80D, 80C, 80B, 80A and 78. To a lesser extent skylight and UV filters also can be used to remove a yellowish tinge from an image. Alternatively, colour film that is designed for different types of indoor and outdoor lighting can be used if flash illumination is not to be utilised (Meehan 1992).

The applications of clinical photography

Photographic images can be used as a reference of tooth position at the start of treatment. Not only do pictures assist practitioners during orthodontic treatment but they can also be used to motivate patients when their enthusiasm and cooperation is waning, often having forgotten why they decided to have treatment in the first place.

Photographs are particularly useful when other pre-treatment records are inappropriate. For example to document the size of diastemas, the position of unerupted or partially erupted teeth and the effects of removable appliances. Similarly the extent of tooth wear before treatment or damage following trauma as well as soft tissue lesions can also be photographed so that the nature and extent of any given condition is clearly defined and can be monitored more objectively. Unusual cases can similarly be accurately documented to that they can be discussed with or presented to professional colleagues at the appropriate time.

Photomontages can also be assembled and booklets made showing the situation before and after treatment and what can reasonably be expected from different treatment alternatives. Parents and referring dentists appreciate béing reminded of nature and extent of the initial orthodontic problems. For the cost of either a duplicate set of prints or the time taken to scan and print before and after treatment pictures, such information can readily be sent to those who require it. With further refinements to video and digital cameras, and the concomitant development of computer imaging and desktop publishing software, it is now straightforward to capture images electronically and include them with correspondence to patients and professional colleagues.

If faced with litigation good quality detailed patient records are essential. Good photographs remove subjectivity from a litigant's claims and can strongly assist a dentist's defence. Legal and insurance reports, if accompanied by photographic documentation of the case, can help greatly in accident and trauma cases.

Development of orthodontic photography

Early orthodontic articles describing photographic technique appeared in the orthodontic literature in the mid-1960's. For example, Silverstein (1967) indicated that he had achieved some excellent results using a Graflex camera with 4" x 5" plate film and lights that heated up both the patient and the operator alike. Many cameras of the time used systems of fixed rods and frames to establish fixed focusing distances. However, despite using such large format cameras, Silverstein advocated the use of the 35mm format. It was seen to be more foolproof and as being a system that subjected the patient to less inconvenience. Technically, 35mm cameras were capable of a greater range of magnifications and capable of more readily checking focus and composition when using standard commercially available cameras and accessories.

Some cameras of the time were single lens reflex (SLR) as compared to range finder, so the image examined through the viewfinder was the same as that finally exposed on the film. More recently available cameras of the time had built in exposure meters and automatic lenses, where the aperture of the lens closed down as the photograph was being taken.

Quigley, Cobb and Hein (1967) detailed an extra-oral and intra-oral system using a Polaroid camera with appropriate attachments and frames to take instant photographs at approximately quarter life size, 1:1, 2:1 and 3:1 magnifications.

Wahl, (1972) alluded to the benefits of taking close-up photographs of study models and a year later Chanda, (1973) documented the advantages of the Orthoscan Camera to record intra-oral images. Chanda considered that the camera was unique in that "Knowledge of photography and lighting was not necessary... as the camera contains its own illumination system and eliminates viewfinders, focusing and shutter adjustments."

Supplementary magnifying lenses, called close-up lenses, which are affixed to the end of the lens distant from the camera body, have also been used in dentistry. However, image distortion, particularly at larger lens apertures, and the need to continually change these attachments, has seen them largely superseded by other optical systems.

Alternatively, special tubes known as extension tubes (Fig. 2), which are inserted between the camera body and the lens to increase the distance between the lens and film plane by predetermined amounts, have also been used for orthodontic photography. These systems initially required the tubes to be changed every time different magnifications were needed. Later tubes, known as auto extension tubes, which could be varied in length and used for a variety of magnifications became available. However, extension tube systems were cumbersome, tedious, time consuming and inflexible to use. They have generally fallen from favour.

Fig. 2. Detachable extension tube.

Greater flexibility in altering the distance between the lens and film can be achieved using extension bellows (Fig. 3). Short mount lenses are used with bellows systems. These lenses do not have a separate focusing ring as the bellows itself can be used to focus the lens by altering the lens to film distance. Alternatively, by fixing the lens to film distance at a predetermined extension, the magnification can be fixed and the image focused by moving the camera towards and away from the object being photographed. Earlier bellows systems required a dual cable release, one to close the lens down to the correct aperture and one to fire the shutter. This had the great disadvantage, when working with small apertures, that the image darkened so much before the photograph was taken that there was no way of knowing whether or not the camera moved after the aperture had closed.

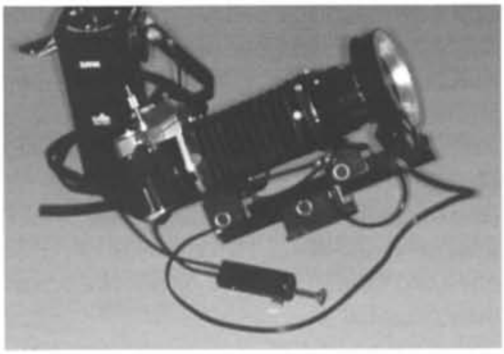


Fig. 3. A bellows attachment.

Automatic bellows that close the aperture and activate the shutter more or less simultaneously were subsequently developed. However, special close-up lenses known as macro lenses have become so refined since the early 1980's that they have almost completely replaced bellows lens systems.

Macro lenses are designed to focus much closer than standard lenses. This enables macro lenses to produce images up to life size, (1:1 magnification), whereas stock lenses can generally produce images up to one tenth life size, (1:10 magnification). Although macro lenses are specifically designed for flat subjects this is largely of academic interest as far as orthodontists as concerned.

Clinical equipment

The Camera Body

The choice of camera body is important for a variety of reasons. Firstly, the choice between film versus digital cameras needs to be made. Furthermore, different types of film cameras use different sized film and produce different size images.

For example, 35mm film cameras produce an image of 24x36mm, medium format cameras produce image sizes of up to 60x70mm and advanced photo system (APS) cameras use a 30x17mm final image size. Moreover, different digital cameras use a variety of different sized photosensitive charge coupled devices (CCD's) to electronically register an image. CCD's are generally one-third, two-third or one and one-third inch in size when measure across their diagonal.

Each format requires a different focal length lens to produce an image of equivalent magnification. A 100mm lens in 35mm format is equivalent to a 160mm lens in medium format or 72mm in APS. A digital camera with a one-third inch CCD needs a lens with a 15mm focal length lens for the same magnification, whereas cameras with a two-third inch or a one and one-third inch CCD require lenses with focal lengths of 30mm and 60mm respectively for images of equivalent magnification.

35mm SLR cameras

35mm cameras have been the most commonly used cameras for a considerable period of time. Single lens reflex 35mm cameras enable a photographer to look at a subject directly through the lens. A mirror mechanism between the lens and the film reflects the image onto the viewing screen. When the shutter release button is pressed, the mirror is raised out of the way so that light can expose the film (Fig. 4). Thus the photographer sees the image almost exactly as it is recorded on film and parallax error is avoided.

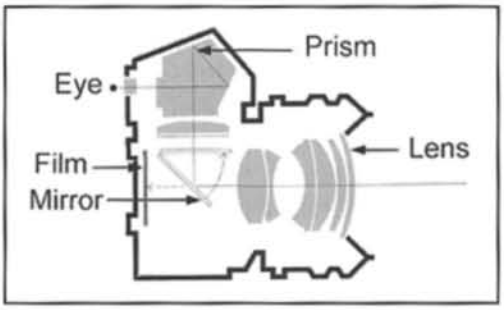


Fig. 4. 35mm SLR.

Most single lens reflex cameras use 35mm film and are heavier and more expensive than equivalent quality range finder models. Historically, by virtue of being the most popular format, these cameras have the advantage of a wide variety of features, accessories and interchangeable lenses, including a variety of macro lenses that make them particularly suitable for orthodontic photography.

Features such as automatic film loading, a motor wind and easy to use focusing screens are desirable. Similarly a data back, which imprints the date or other clinical details, is a useful feature when cataloguing or presenting clinical material.

APS cameras

Advanced Photo System cameras are aimed to make photography simpler and more accessible than the 35mm format. Although initially aimed at the snapshot market, the APS system has plenty of room to grow and this system is being developed in tandem with the 35mm format.

Features that differ from 35mm SLR cameras include self-loading cassettes which automatically rewind when the film is finished. Once at the lab, loading the film into the processor is automatic and, after processing, the film is again automatically returned to the cartridge, which is used as the permanent negative storage holder. The film is returned with a series of index prints so that one can arrange enlargements or re-orders. The cartridge is also designed to make it easier to load your photographs into a computer or view them on television by using dedicated film scanners and television accessories (Eastaway 1996a).

APS allows the choice of three formats known as classic, group and panoramic producing prints from 9x13cm to 9x25cm. During manufacture a machine and human-readable number is assigned to both the cartridge and the film inside. This number is printed on the back of every print as well as the index print. This number, can be used by the lab to produce re-orders and enlargements.

At the end of the film cartridge, a rotating circular "data disk" tells the camera the film speed, type and exposure length. At the other end a film status window indicates if the film is unexposed, partially exposed, fully exposed or processed. This allows mid-roll film changes to be made with some cameras.

APS film also has magnetic strips above and below the image area which are available for recording data. The top strip is used by the lab, the bottom strip by the camera. At the time the exposure is made, the camera can indicate whether or not a flash was used, whether there was artificial illumination, the level of brightness, and the magnification of the image. This information is then used during processing to determine optimum colour balance and print density for each photo. This system also ensures that reprints and enlargements look exactly the same as the original.

More data can be stored detailing the date and the time of exposure, camera settings, roll title and captions. This information can be transferred to the back of the print. In the future more information may be stored onto the film. If the entire film surface is coated, there is room for up to 80kb of data on a 40 exposure film.

Some APS camera bodies can be used with the currently available 35mm lenses and equivalently featured camera bodies in 35mm and APS formats cost similar amounts. When using standard 35mm lenses the effective focal length of the lens is increased by 25% when attached to an APS camera body because of the different final image size between 35mm and APS cameras,. For example, a lens that has a focal length of 100mm when used on a 35mm camera body has a focal length of 125mm when used on an APS camera.

The disadvantages of the APS system is that no transparency film is currently available and greater image enlargement from the negative results in poorer image quality. Photographic prints as well as both 35mm films and APS films can be scanned in flat bed or film scanners for the electronic inclusion of images into documents. However, the greater magnifications required for APS images means that there would also be greater degradation of final image quality when these films are used.

The Camera Lens

Adequate magnification

The camera's lens forms the image that is projected onto the surface of the film. The image produced by the lens can be larger or smaller than the original subject. The magnification produced by a lens depends on its focal length, a measure of its magnifying power, as well as the distance between the lens and the subject. Most lenses have a focusing mechanism to either bring the image into sharp focus or, in the case of a macro lens, set the magnification ratio of the image on the film plane.

For both intra-oral and extra-oral photographs a lens with a focal length of 90mm to 135mm is generally considered the best focal length for close-up clinical photography. The longer focal length improves the working distance from the subject. This makes intra-oral posterior photography easier and more comfortable for the patient. It also keeps the camera at a sufficient distance from the patient's mouth so as not to interfere with the sterile environment or be fogged by the patient's breath.

Depth of Field

In addition to forming an image, the camera lens also controls the amount of light that strikes the film. A roughly circular diaphragm incorporated into the lens barrel and operated by a lens collar, masks out part of the outer circle of the lens, reducing its effective diameter. The diaphragm determines what part of the maximum diameter is used to allow light to pass through the lens (Fig. 5).

The f-stop is a measure of the degree to which a lens transmits light. An increase in the f-number by one increment, for example from f4 to f5.6 or from f16 to f22, halves the amount of light that passes through the camera lens. Altering the aperture of a lens provides a means of exposure control and it affects the degree to which objects in the photograph are in sharp focus. All camera lenses have a critically sharp focus that is limited to the point or plane on which the lens is focused. Everything in front of or behind that plane of focus must necessarily be somewhat out of focus and blurred. However, in practical terms there is a region or field of acceptably sharp focus that extends in front of and behind the point of focus. This is referred to as the depth of field.

A

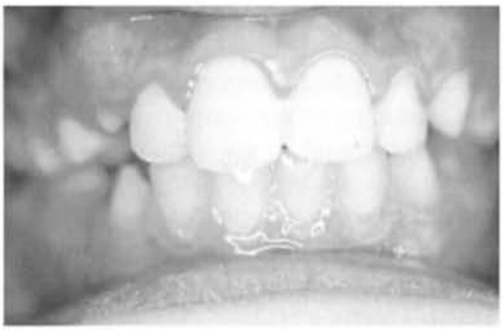
B

Fig. 5. A & B - Variations in lens diameters will determine the amount of light reaching the film.

Depth of field is a function of the image magnification, the aperture at which the lens is used and focal length of the lens.

Increasing the magnification of an image decreases the depth of field. Closing down the lens diaphragm increases depth of field. Each time you double the f-stop, for instance from f16 to f32, you double the depth of field. Increasing the focal length of a lens decreases the depth of field by the square of the focal length of the lens. For example, doubling the focal length of a lens from 50mm to 100mm, reduces the depth of field to one quarter. Trebling the focal length of a lens from 50 to 150mm reduces the depth of field of the lens to one ninth.

A



B

Fig. 6. A - Molars in focus at f32.
B - Molars not in focus at f4.

Clinically, to provide sufficient depth of field to have both anterior and posterior teeth in focus when taking anterior intra-oral views an aperture of f32 on a 105mm macro lens is ideal. For close-up photography the depth of field extends equidistantly from the point of critical focus and, as such it is necessary to focus in the region of the premolars to have as many teeth in focus as possible. An aperture of f22 has a depth of field approximately two thirds that of an aperture of f32. This provides a reduced margin of error when focusing and may be insufficient for patients with large mouths (Fig. 6).

Another clinical consideration is that it is best to use a macro lens that focuses from infinity to life size, rather than from infinity to 1/2 imes life size. This avoids the inconvenience of using additional extension tubes, plaçed between the camera body and the macro lens, to achieve maximum magnifications.

Certain considerations also relate to auto-focus lenses. These lenses, which are more expensive than manual focus lenses, sense the distance between the camera and the object and adjust the focus of the lens accordingly. However, in macro photography altering image focus also alters the final magnification of the image so that consistent image magnifications become difficult, if not impossible to achieve. Auto-focus lenses also focus on that part of the object that is centrally placed within the field of view. For intra-oral photographs this is usually that part of the mouth that is placed closest to the camera lens. As such, unless the operator focuses on the premolars first, locks the focus and recomposes the image, only half of the available depth of field will be utilised and the posterior regions of the mouth will not be sharply in focus.

The Flash Unit

Illumination for intra-oral photography is generally achieved by means of a lens mounted flash. Generally either a point source or ring flash is used for close-up lighting.

Point light sources, located on the end of the lens provides a shadow casting light that reveals topography, shape, and contour. These light sources can be rotated around the lens to avoid unwanted shadows caused by patients' lips and cheeks. However, some diligence is required to ensure that the flash is positioned optimally for each and every photograph that is taken. Alternatively, a dual flash system can be used but this reduces the 3-D nature of a single point light source.

By contrast, ring flashes flood the subject light and produces an image without shadows. This produces a flatter looking image that lacks topography. Generally ring flashes are easier to use and more fail-safe than their point flash counterparts and are generally recommended for intra-oral photography. However, they are generally not as powerful as available point light source. Larger lens apertures or faster film may be required for properly exposed images.

The purpose of flash illumination is not only to cast light on a subject but also to provide enough light so that the aperture can be stopped down to provide an adequate depth of field. Every flash unit has a guide number that indicates the amount of illumination provided by a flash. Mathematically, dividing the guide number by the distance in metres between the subject and the flash gives the correct aperture for the proper exposure of 100 ISO film.

Theoretically, to properly illuminate an object at half magnification the flash to object distance will be about 250mm depending on the lens system used. If a small aperture of f32 and 100 ISO film are selected then a flash unit with a guide number of 8 will be required. (GN8 / 1/4 metre = f32). However, the intensity of light passing through a lens and striking the film decreases as the distance between the lens and the film increases. The aperture setting designated by the guide number is based on the assumption that the distance between the lens and film is approximately equal to the focal length of the lens. If you are using a bellows system, for example, you must give the film more exposure for the consequent fall-off in light intensity.

The increase in exposure needed is calculated by the following formula (Schaefer 1995):

- Bellows Extension Factor = (Bellows Extension)^2/(Focal Length)^2

Where the bellows extension is the distance between the lens board and the film plane. Thus if you are using a bellows system where the film to lens board distance is 136mm (a magnification of approximately 1.5x using a 100mm short mount lens) the bellow extension factor will be $(136)^2/(100)^2$ = 1.85. This means that you need to double the exposure either by opening the aperture one stop or by using a more powerful flash. However, opening the lens by one f-stop decreases the depth of field so a stronger flash unit is a better alternative.

Because of the bellows extension factor the flash unit in this example needs to be powerful enough to adequately expose the film at an aperture one f-stop smaller than would ordinarily be anticipated, an aperture of f45 rather than f32. The guide number required thus calculates to be 11 1/4 (GN11 1/4/ 1/4 metre = f45).

The bellows extension factor for 1/2x and 1x magnification calculates to be 1 1/2 and 3x respectively. Extension tubes lose a similar amount of light at greater magnifications. Macro lenses, similarly need more light at greater magnifications and generally lose at least one f-stop in focusing between infinity and maximum magnification. A flash unit with a guide number of 13 or more is advisable if 100 ISO film is to be used to

ensure sufficient illumination at all clinically used magnifications. It should also be noted that when using intra-oral mirrors opening the aperture one f-stop is required because of the increased flash to subject distance.

Types of flash unit

Flash units can also be categorised as simple, automatic, dedicated or TTL. All flashes need calibration before being used clinically. This involves using the flash unit at different settings such as full, 1/2 and 1/4 power and selecting different lens apertures, evaluating the resulting film exposures and choosing the settings giving correct exposure.

Simple flashes, once calibrated, are reasonably foolproof. However, no mechanism exists with these flash units to warn the operator about any over- or under-exposure that may occur.

Automatic flashes use a photoelectric cell to record the amount of light reflected from the subject and attenuate the flash as appropriate for any particular situation. The disadvantages of such a system are twofold. Firstly, many of these flashes dictate the lens aperture to the user, whereas in clinical photography the user must be able to control the aperture. Secondly, the proximity of the subject fools the electronics when used for close-up work, so photographs are usually under-exposed.

Dedicated flashes use a sensor either located in the flash unit or the camera itself. Connecting the flash unit to the camera and selecting an automatic mode will select the camera's shutter speed and aperture automatically. Thus the limitations associated with automatic flash units apply to dedicated flash units as well.

More recent flash units work in conjunction with a flash sensor mounted within the camera to receive light reflected off the film. In this way total automation is possible as light is measured after it has passed through the lens (TTL) at any selected aperture and through any accessories such as extension tubes. More sophisticated systems also give information on over- or under-exposure conditions. Hence these systems are more foolproof than the other three and should be considered the flash units of choice (Wander and Gorden 1987) (Fig. 7).

Fig. 7. A typical ring flash with through the lens metering (TTL).

The problems of incorrect colour casts are largely overcome when flash units are used. This is because flash sources are generally colour corrected for daylight at noon. However, minor colour correction may be necessary as the interplay between the light from the flash unit, the colouration of lens coatings and film emulsions may cast a hue over the final image. This will be more noticeable for slide film because there is no facility for correcting the colour of the final image during film processing.

Clinical technique

Once the equipment for taking clinical photographs has been chosen, consistency in results relates primarily to using a standardised technique. Procedures also need to be set in place to detect any problems

that may arise from for example, flat batteries or wrong camera settings.

Before using the equipment routinely on patients, some time is needed to calibrate the equipment, select the film to be used as well as any colour correction filters that may be required. Trial and error, using a variety of aperture and different flash settings with different speed films from different manufacturers is the only way to evaluate the most appropriate system to meet your needs for both intra-oral and extra-oral photos. Once final magnifications and exposure settings have been decided upon then they need to be recorded for future reference.

Before each patient is photographed ensure that all camera and flash connections are firm, especially if the camera has been transported before use. Batteries also need to be checked, particularly those in the flash unit to ensure that these are fresh. Also check that the camera is set to the correct shutter speed, or correct mode if the camera is automatic and finally that the setting for the film speed is correct.

After film exposure, check for any warning lights if a TTL metered flash system is being used. If in doubt retaking photographs immediately is the best precaution. The patient's name, the photographic view taken and the exposure number on the film all need to be recorded to assist the cataloguing of photographs at a later date.

FACIAL PHOTOGRAPHY

Diagnosis and treatment planning in orthodontics has traditionally used an analysis of true lateral cephalometric films as a diagnostic tool (see Chapter 6). However a cephalometric analysis provides only a limited record with no information about the actual curvature of the face and facial photographs are essential to complement the cephalometric film as people rarely see themselves in profile. Standardised photographic records are required for accurate reporting of treatment stages and provide an opportunity for meaningful comparison of these stages.

Background

For ideal colour balance, colours should be chosen which complement the subject being photographed. A pale blue background is preferable as colours with toning similar to facial colours will lack contrast.. Ideally an area should be designated for facial photography and the simplest approach is to paint the wall.

When using a point source of light such as flash, a "halo" will be produced around the head and this will be more noticeable when pale backgrounds are used. Using a flash can also produce "red eye" when taking a full frontal picture. A wide open aperture will reduce the amount of light required to expose the film although this will reduce the depth of field. Alternatively, faster film speeds can be used which allow pictures to be taken without the use of a flash, especially where secondary light sources are installed in the room. Colour correction may be required to compensate for the artificial light by means of filters placed over the camera lens.

Lenses

A standard portrait lens has a focal length of 105mm and lenses between 100 and 135mm are satisfactory. Such lenses provide an image with little distortion that closely resembles the view from the naked eye. A 50mm lens will produce a distorted image and will require and closer subject to camera distance to fill the frame (Fig. 8A, B & C).

A

B

C

Fig. 8. A - Facial photograph: 28mm lens
B - Facial photograph: 50mm lens
C - Facial photograph: 135mm lens

Natural Head Position

"Lorsqu' un homme est debout et que son axe visuel est horizontal il est dans l'attitude naturelle" (Broca 1892). Natural head position occurs when one looks at the horizon. This visual axis has been adapted to orthodontics and cranio-facial morphology (Solow & Talgren 1976). Such a visual axis can be created by looking in your own eyes in a mirror at a standard distance of 1.5 metres (Moorees and Kean 1958). Use of natural head positioning provides a frame of reference outside the cranium that is reproducible and simple to establish.

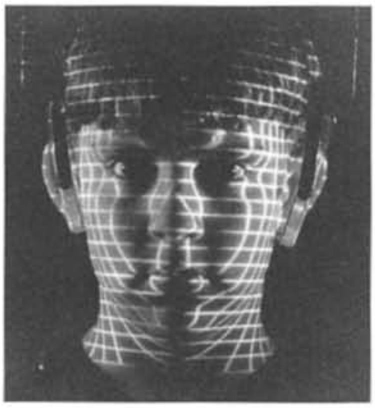
Positioning the Patient

For meaningful records which allow pre and post-operative comparison, subject distance, head positioning and lens should be standardised (Fricker 1982). The patient camera distance should be 1.5 metres with the camera at the same height as the subjects eyes. The patient should be standing erect and in the natural head position located using the visual axis. Such an axis can be located by placing a mirror in front of the camera which is then swung away for the photograph.

Claman, Patton and Rashid, (1990) compared the effects changing the focal length of the lens as well as the effects of altering of head, camera and jaw position to assess the contribution of each factor to final picture. Alterations in mandibular position of as little as 1.8mm could be detected in lateral view while differences of as much as 7.5mm were difficult to observe from the front. They also noted difficulty in distinguishing a protrusive jaw position with a forward head tilt from a retruded jaw position with a backward head tilt. Conversely, actual changes in jaw position can be accentuated through non-standardised photographic techniques and as such some form of standardisation is mandatory.

An apparatus has been designed to fix the camera subject distance and stabilise the head position on an adjustable mount (Fricker 1988). To standardise the 3/4 and profile views a mark is placed on the cheek adjacent to a reference line on the head stabiliser so that as the subject rotates to 3/4 and profile, the same orientation of the head is maintained with a horizontal visual axis.

Projection of bilateral grids for a full face view will produce a contour map of the face which facilitates facial analysis and description of facial type. Such contours then allow three dimensional mapping of the face and assessment of asymmetry (Fig. 9A & B).



A

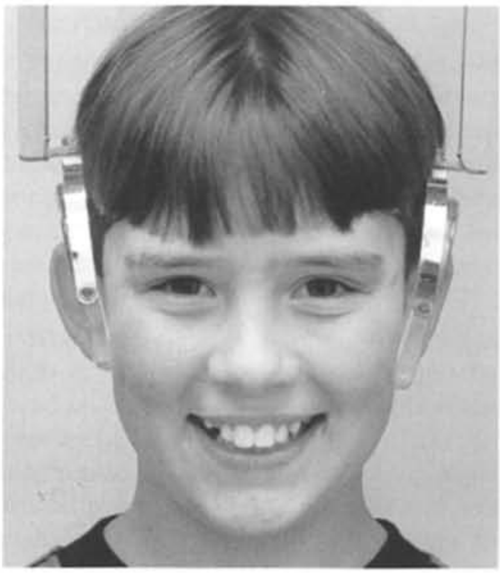
B

Fig. 9. Frontal view, contour photographs.

A - Symmetrical.

B - Asymmetrical.

A standard set of facial views are then produced in full face 3/4 and profile (Fig. 10). The film used in these photos has a speed of 400 ISO which allows for good photographs without the use of a flash and will eliminate unwanted shadows.



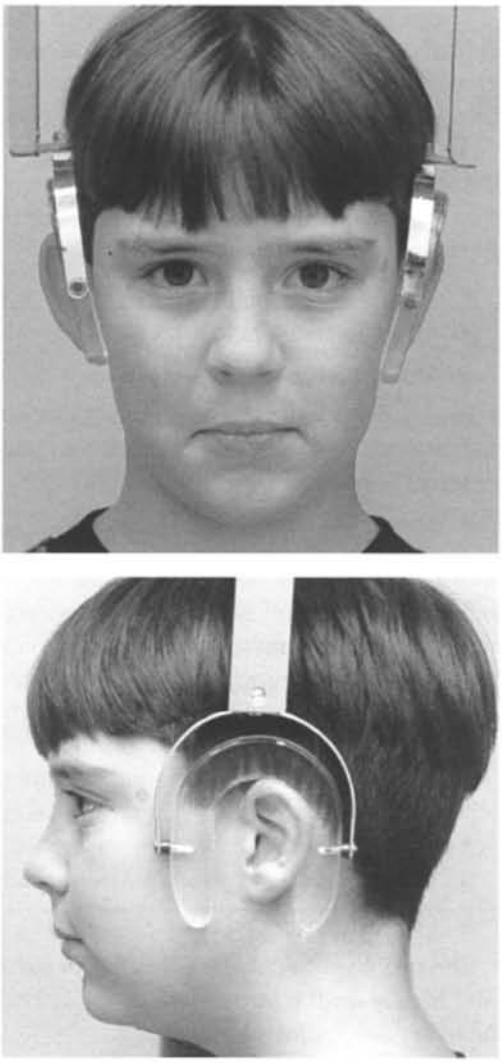


Fig. 10. Standardised views 1.5 metres, 105mm lens

Photographic Analysis

The analysis of symmetry or lack of symmetry is a fundamental principle in the assessment of facial aesthetics. Dividing the face into thirds will provide a framework for analysis as per Leonardo Da Vinci (Fig. 11). For the analysis of the relationship between the craniofacial skeleton and the soft-tissue facial contours, profile and frontal photographs are taken under standardised conditions and traced.

Fig. 11. Facial proportions as described by Leonardo Da Vinci.

Schwarz (1955) devised an analysis of the facial profile based upon the construction of three reference planes (Fig. 12):

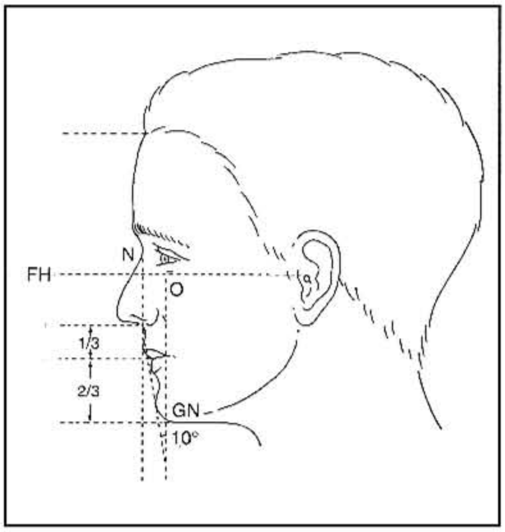


Fig. 12. A line (PN) is drawn through skin-nasion (N) perpendicular to the Frankfort Horizontal Plane (FH) similar line (PO) is drawn through orbitale (O). The underside of the chin is projected onto PN at GN. Between PO and PN is the "Jaw-profile field".

1. Eye-ear plane (Frankfurt horizontal plane);
2. Skin nasion perpendicular
3. Orbitale perpendicular

In an ideal average-value face the subnasal point touches the skin nasion perpendicular. The "soft-tissue chin point"(the most ventral point of the soft-tissue part of the chin) lies in the centre of the "jaw-profile field", the "skin gnathion" (the most inferior chin point) lies on the orbital perpendicular.

Depending on the location of the subnasal point relative to the skin nasion perpendicular, there are typical profile variations: Average face= subnasale lying on the skin nasion perpendicular; anteface=subnasale lying in front of the skin nasion perpendicular: retroface = subnasale lying behind the skin nasion perpendicular.

Facial Types

The classification of facial types is based on the variations of facial length to facial width. The length is taken from the soft tissue nasion (nasal bridge) to the menton (tip of the chin). The width is the greatest width across the zygomatic arches. The index is thus the length as a percentage of the width.

- Europroscopic- square or short, index 80 or less
- Mesoproscopic- average, index 85-90
- Leptoproscopic- long, index 90 or more

The cephalic index is the cranial index of length of cranium to width of cranium when looking from above.

- Brachycephalic- square
- Mesocephalic- average
- Dolichocephalic- long

There is little correlation between the cephalic index and the facial index, ie. one can be both brachycephalic and leptoproscopic. More recently terminology of facial types have followed the terminology of the cephalic index. The following terminology for facial morphology is less confusing and is recommended (Collett and West 1993)

- Brachyfacial-square
- Mesofacial- average
- Dolichofacial- long

Facial photographs may be produced either digitally or with film. Either way the criteria for good photographs is:

- sharp definition
- good depth of field
- accurate colour rendition
- correct illumination
- good framing (Crawford 1987)

A standard set of facial photographs for orthodontics should include:

- full face relaxed
- full face smiling
- 3/4 view relaxed
- 90° true profile relaxed

The profile view may be either left or right and ideally be the same view as the lateral head cephalometric view.

Facial Divergence

Another analysis of the lateral photograph is based upon evaluation of the divergence of the face. Two reference lines are used: (1) A line joining the forehead (glabella) and the border of the upper lip; (2) the line joining the border of the upper lip and the soft-tissue pogonion.

The following three profile types are differentiated according to the relationship between these two lines (Fig. 13):

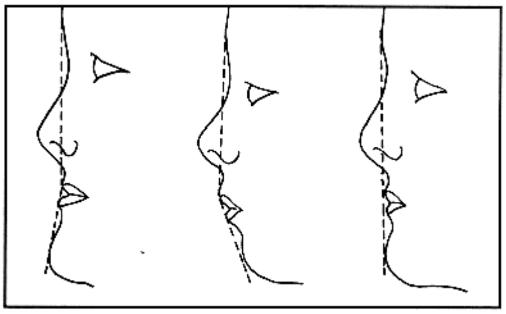


Fig. 13. Straight profile, right: The two lines form a nearly straight line. Convex profile, centre: The two reference lines form an angle indicating a relative backward displacement of the chin (posterior divergent). Concave profile, left: The two reference lines form an angle indicating a relative forward displacement of the chin (anterior divergent).

Frontal Analysis

An analysis of the frontal picture is important in assessing major disproportions and asymmetries of the face in the transverse and vertical planes. Even a slight rotation of the head from the plane of the film can result in major discrepancies between the relative patterns of the right and left facial contours. It is, therefore, absolutely essential for the camera to be placed perpendicular to the facial midline during the exposure.

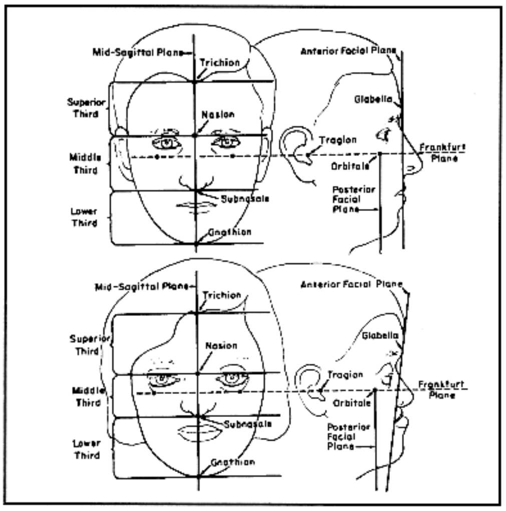


Fig. 14. Above normal anthropometric chart to contrast with that of a patient with Crouzon's disease, below. (From Flemming 1971).

Once again, the face is divided into thirds and further divided to assess the proportions between the nose lips and chin. A mild degree of asymmetry between the two sides of the face exists in nearly all normal individuals and such an analysis should be balanced with a subjective analysis of facial aesthetics (Fig. 14).

Intra-oral photographs

A full set of intra-oral photographs ordinarily comprises a frontal view of the teeth, left and right buccal views as well as upper and lower occlusal views (Fig. 15).

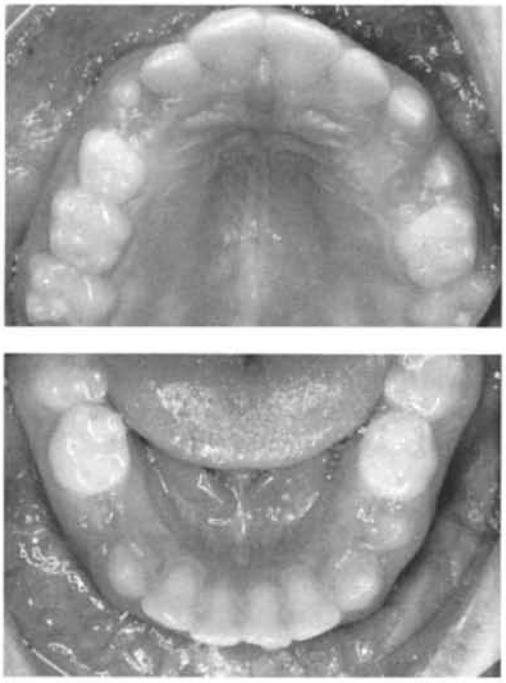


Fig. 15. Standard set of intra-oral views, frontal lateral left and right upper and lower mirror occlusals.

Magnification

The magnifications most commonly used for intra-oral photography vary from 1:2, when a macro lens that provides only half magnification is used, to 1:1.5 when a system allowing more powerful magnification, such as a 1:1 macro lens or a 1:2 macro lens with extension tube is used. Provided that the magnification is consistent for all photographs the choice is largely one of personal preference. However, the picture is best when free from peripheral distraction (Crawford 1985).

Lip retractors

Many lip retractors can only be cold sterilised, now largely considered unsatisfactory for adequate infection control. As such, ensure that any lip retractors used can be properly sterilised.

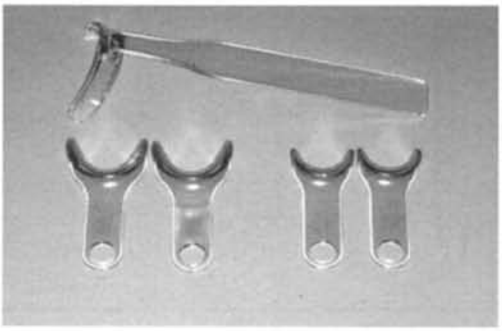


Fig. 16. A standard set of lip retractors for intra oral views.

When retracting a patient's lips it is important to keep the retractors in line with each other so that a straight line can be drawn from the end of one retractor across the face of both retractors to the end of the other. Frequently retractors are folded too much against the patient's face and this fails to reflect the patient's lips and cheeks sufficiently from their teeth. This in turn results in poor illumination of the teeth and an increased amount of extra-oral soft tissue in the field of view, both of which are undesirable.

It should also be remembered that lip retractors hurt when the retractors used are too large, when the lips and cheeks are retracted too hard or when the lips are pulled in the wrong direction. This is particularly so for patients with either small mouths, or tight lips. It is important to select the right retractors, explain what you're doing and accept a compromise image if necessary before tears arise.

Intra-oral Mirrors

Mirrors are generally used for upper and lower occlusal views but may also be used for left and right buccal photographs as well. General guidelines to remember are that mirrors always reverse images and as such, mirrored images are more logically stored

reversed. That way when viewing these images the left buccal segment, for example, looks the like it should and occlusal views appear the right way around.

Mirrors scratch easily particularly if wiped with paper towel and fog unless either coated with a demisting solution or heated in warm water first. The largest mirror that fits comfortably into the patient's mouth should be used as should mirrors that are autoclavable.

A

B

Fig. 17. A - Lip retraction for frontal view.

B - Lip retraction for lateral views.

Anterior view

Set the lens to the required aperture and magnification and move the camera forwards and backwards until the canines appear in sharp focus. Reframe the image such that the occlusal plane is kept horizontal and the mesio-incisal corner of the upper central incisors is place in the centre of the field of view. This standardises the magnification of the image and optimises the available depth of field (Fig. 17A).

Some practitioners find the additional illumination provided by the dental light useful to help focusing and framing the final image. However, if the dental light is used then a yellow cast may appear on the final image, which requires colour correction using a blue colour correction filter and possibly a change in exposure.

Buccal views

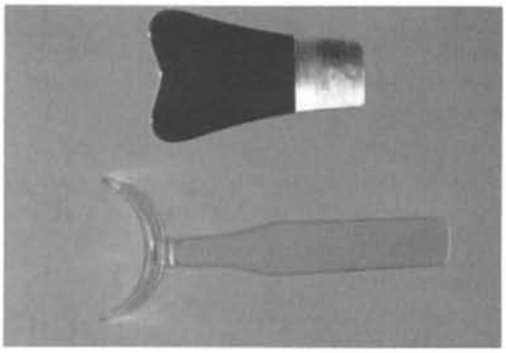
Views of the left and right buccal occlusion are generally taken using the same magnification as is used for the anterior views of the dentition. However, the photographs can be taken either directly or by using intra-oral mirrors. The advantage of direct photography is that the image appears as it does in the mouth, whereas using mirrors the image is reversed. With direct vision problems of mirror fogging can also be avoided. However, direct photography does require more cheek retraction, which can be a problem, particularly with patients who have tight lips and small mouths. A large retractor should be used anteriorly with a small retractor placed posteriorly if possible to keep the lips and cheeks away from the teeth (Fig. 17B).

When framing a left or right buccal occlusion the central and lateral incisors on the side distant to the camera should be in view but the canine should not be included unless it is severely mesio-buccally displaced. The camera lens should be kept parallel to the buccal segment being photographed and the cant of the occlusal plane kept mid-photo and parallel to lower border of the frame. The first molars should be included in picture if possible. Focus on the canine or premolar

region to ensure an optimal depth of field and then reframe the picture to produce the desired result.

Occlusal views

A "U" shaped lip retractor (Dr J Jenner, Adelaide) is the best alternative to retract the lips away from the teeth. Having placed the retractor position the occlusal mirror with the rear of the mirror distal to the first molars. A magnification slightly less than that used for other intra-oral views and some practice is needed to angle the mirror and camera correctly so that sufficient magnification can be maintained. When taking lower views ask the patient to curl their tongue backwards behind the mirror so that sub-lingual tissues appear in the field of view (Fig. 18A & B).



A

B

Fig. 18. A - A Jenner lip retracter and mirror.
B - Taking occlusal views.

Focus on the premolar region by setting the magnification on the lens and moving the camera towards and away from the mirrors until the premolars are in sharp focus. This standardises the magnification of the image and makes best use of the available depth of field. Open the lens aperture one f-stop, from the other intra-oral views to allow for the decreased magnification and increased distance that the flash illumination needs to travel because it is bounced off the mirror.

DIGITAL PHOTOGRAPHY

With the advent of more affordable digital technology, filmless cameras now provide a viable alternative for taking clinical photographs. The time and cost savings of filmless photography, eliminating the variability and environmental concerns associated with chemical processing, as well as the convenience of not having pictures processed at film laboratories, makes digital photography seem appealing.

However, digital photography is not currently poised to completely replace conventional film based systems and considerable money and effort is being spent by photographic companies to further refine film and film based camera systems. The initial costs involved, limitations in shooting flexibility, storage capacity of cameras and the associated compromise in image quality also deters some practitioners from embracing digital technology.

How digital cameras work

Digital cameras take photos without film. Their image capture medium is a photosensitive semiconductor called a charged coupled device (CCD) which is composed of several hundred, and sometimes many thousand, separate photosensitive elements. CCD's transform

light into electrical charges whose intensities vary based on the strength of the light reflected from the image being captured. The CCD passes these charges to an analogue-to-digital converter that codes the light data for storage in the computer's memory or on a hard drive (Eastaway 1996b).

However, the type, size, performance and cost of CCD's, and by extension filmless cameras, varies greatly. Some cameras, known as studio digital cameras, use a linear CCD, a single row of photosensitive elements, to capture images in a series of narrow strips. This technique offers high resolution but it may take up to several minutes for one exposure. Linear CCD's cannot be used to photograph moving subjects; nor can a subject be shot that can't withstand a slow exposure under bright, hot studio lights and consequently such cameras currently have no orthodontic application.

Real-time cameras use a CCD array that exposes the entire grid of photosensitive elements at once. A CCD array rivals normal photographic film in image-capture speed, but a CCD array creates an image with much lower resolution than film or a linear CCD (Fig. 19).

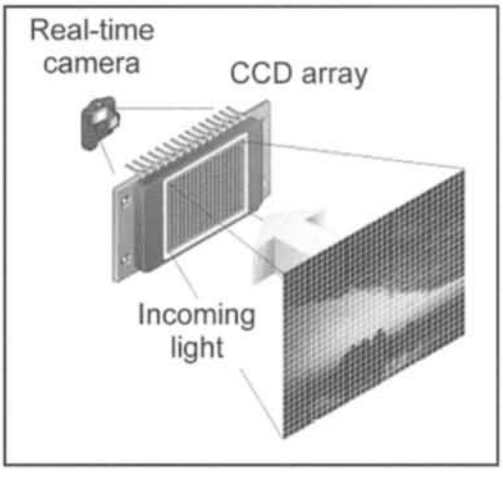


Fig. 19. Real-time camera.

To capture colour incoming light must pass through filters before reaching the CCD. One way to handle filtration is to make separate exposures through three filters, each one impeding one of the primary colours that makes up the digital image. This technique produces good image quality, but it's slow and some CCD's have difficulty registering the separate red, green and blue colour images.

Some digital studio cameras use embedded filters where three rows of filters sit directly on top of the photosensitive elements. Each filter row blocks a different primary colour and the CCD captures all three colours in one pass thereby eliminating the registration problems found in the three-pass systems.

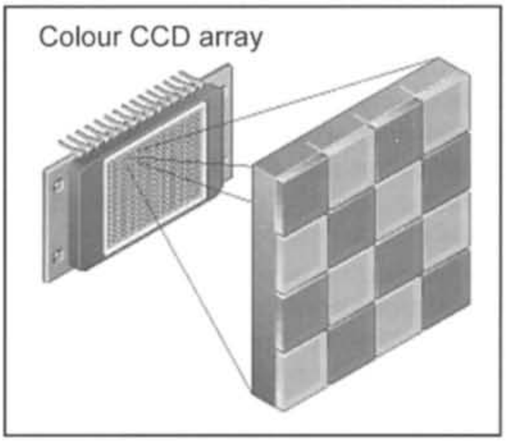


Fig. 20. Colour CCD array.

Some digital cameras are technically analogue-type still-video cameras. Whereas digital cameras instantly convert images from analogue to digital data, still-video cameras need expensive boards or boxes to produce their digital data. Still-video cameras generally yield poorer image quality at the same resolutions as digital cameras. However, still-video cameras offer the advantage of being able to be instantly output a standard video-broadcast signal to a TV, VCR or colour video printer.

To get better resolution, real-time cameras can use a multiple-array system. A prism directs light from the image source onto two or three arrays, which have various embedded pattern schemes for filtering the primary colours. The information from each array is combined to create one colour image whose resolution equals that of the images captured with a single monochrome array. A multiple-array system can't capture images in rapid succession. The data from just one shot fills the RAM buffer and needs to be cleared before shooting again. As such these types of cameras are not currently suitable for orthodontic imagery.

Most real time cameras use colour CCD arrays with embedded filters arranged in a pattern. Each photosensitive cell captures just one of the primary colours. For each pixel of an image the camera must interpolate from nearby elements to get the other two colours. This method which is used by some of the most advanced and expensive digital cameras, permits instant exposure but reduces image resolution (Fig. 20).

However, it is important to also recognise that the quality of the image from a digital camera not only depends on the system of image production and the size and quality of the CCD. It is equally dependent on the optical quality of the camera lens.

Point and Shoot digital cameras

The cheapest digital cameras have been designed for family use and home computer users wishing to take advantage of digital technology. More expensive cameras in this range have been designed more for business use and hobbyists. Generally these more expensive cameras have a better quality CCD, a through the lens liquid crystal display (LCD) and may even have a zoom lens. However, the lenses they come with may have an inappropriate focal length for clinical use. If the zoom is digital rather than optical, then using the lens for close-up could result in images that are unacceptably pixelated.

The CCD's of many currently available Point and Shoot cameras measure approximately 4.5mm x 6.5mm and contain up to 810,000 pixels in a 1024 x 768 array.

Lens interchangeable SLR-type digital cameras

Lens interchangeable SLR-type digital cameras are currently the top end of the digital camera range. Despite their cost they produce an image containing less information than a conventional 35mm camera costing only a fraction the price of the digital alternative. The highest quality images produced by these cameras generate files of such size that they are difficult to store and unwieldy to manipulate and print.

In standard 35mm SLR cameras the final film image is 36mm x 24mm. However, the size of CCD's used in lens interchangeable SLR-type digital cameras is less than this. Consequently, Reduction Optics is required to modify the focal length of the lens so that the image size matches that of the CCD. Because of the Reduction Optics, not all 35mm SLR lenses will be completely compatible with a given digital camera body and may adversely affect the image that is produced. Such image degradation may vary from a slight dimming at the edges of the image at certain apertures and focusing distances, to more pronounced vignetting of the image. It is always necessary to check a manufacturer's specifications and recommendations and thoroughly test a proposed system before purchasing a lens interchangeable SLR-type digital camera system to ensure that the macro lens system you are considering will provide the quality of images you require.

Choosing a digital camera system

Digital orthodontic photography is not yet as well established as conventional film based systems. Improvements in digital camera systems are occurring continually and at a more rapid pace than conventional film based systems.

When comparing different digital cameras the features to look for are not dissimilar to their conventional film based counterparts. However, many digital cameras are available as complete units rather than separate components of camera body, lens and flash.

Camera body

For intra-oral work a through-the-lens preview system is necessary and may be provided by a through-the-lens viewfinder or by a liquid crystal display (LCD) on the camera back. The size and resolution of any such LCD is important in properly framing the image.

The size, sensitivity, quality and resolution of the CCD will largely be fundamental to the final image quality. The ISO system is used for to rate the CCD's sensitivity and this may vary from anywhere between 100 ISO to 1600 ISO depending on the type of CCD used. The resolution of a camera's CCD also varies greatly. A CCD with a resolution of 1280x1024 pixels produces noticeably give better quality images than 640x480 pixel arrays. The trade off is that better quality images are generally synonymous with larger file sizes that take more memory to store and more time to load into the computer, manipulate and print.

The amount of internal memory available for programs and picture storage also needs to be considered. Limited internal camera memory means that less sophisticated camera software and fewer or smaller image files can be stored at one time. The availability of additional memory cards and the quality of the image manipulation and application software need to be assessed.

A TTL light metering system is preferable to ensure proper exposure when flash photography is used. The ability to link an external flash using a hot shoe or flash synch cable allows a secondary flash unit, such as a ring flash, to be employed. If such an attachment is not available then a slave unit, which detects the firing of a camera's internal flash is required to fire a secondary flash source.

A data back, which imprints the date or other clinical details with the digital image, is also a useful feature when cataloguing or presenting clinical material. Although systems of video or digital projection are becoming more common-place, any images requiring projection using a conventional 35mm projector will need to be converted to 35mm format at a computer slide bureau beforehand.

Lenses

The quality, aperture range, maximum and minimum focal lengths of optical zoom lenses, and the minimum focusing distance of the lens all need to be considered. Select a camera that has a lens with a focal length equivalent to 105mm on a 35mm camera. If the camera has a zoom lens with a maximum focal length of 105mm then use of maximum zoom will readily standardise magnification. If the lens has a zoom greater than 105mm then some calibration showing the focal length of the zoom lens is necessary. Otherwise each time the camera is used extreme care will be needed to ensure that the lens focal length, once set, is not changed. If the lens is accidentally zoomed in or out then some method is needed to re-establish the chosen lens focal length before further photographs are recorded.

Ensure that the lens has a macro function and that it will still focus at the distances required for intra-oral photography. A minimum aperture of f32 is desirable to provide adequate depth of field. Lenses, which are purely autofocus, may also prove more difficult to use than those with a manual over-ride. They will automatically focus on that part of the object placed centrally in the field of view and, without some form of focus lock, will not have sufficient depth of field to be serviceable clinically.

Digital zooms, as compared to optical zooms, work by electronically magnifying the pixels forming the unmagnified image. They cause considerable image degradation at greater zoom magnifications. As with conventional cameras, totally automatic systems are good for general photography but some form of manual over-ride greatly enhances the flexibility of and control over the camera system.

When data describing an image is stored to and accessed from computer hard drive the way the information is manipulated by the computer so that the image is represented digitally is important. Images can be stored in a variety ways and the digital format representing the image depends on the computer software programme used to generate the computer file. Different computer software programmes use different mathematical algorithms to produce the different file formats. Historically the most commonly used file formats have been the .BMP, .TIF, .WMF and .JPEG image files. For example a picture called "FACE" in .BMP format would appear as "FACE.BMP" on the computer hard disk drive. It could only be decoded by a software programme capable of processing the .BMP algorithms and regenerating the image from the digital information stored within the file.

Different file formats have different advantages and disadvantages. For example, the .JPEG file format has the advantage that it compresses the image as it is stored to disk. The greater the compression the smaller the file size, the more images that can be stored in a given amount of memory and the faster files can be downloaded to computer. However, the disadvantage to this is that the file needs to be decompressed before it can be viewed, which takes time and, with compression ratios of greater than about 10:1, the images start to become noticeably degraded to the human eye.

The number of images that can be stored in the camera before unloading them is important as is the method by, and the rate at which, files are transferred to the computer. Many cameras use additional memory cards that greatly enhance the number of images that can be stored before the image needs to be downloaded into a computer. A point to note is that some cameras will also automatically erase images after they have been stored for a predetermined time, sometimes as little as a few days.

Finally, a catalogued system of storage is required. Although computer hard drives with considerable capacity as well as backup drives are relatively cheap a systematic method of storage with appropriate backup is required to ensure that valuable data is not completely lost if a hard drive crashes.

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5 Orthodontic Radiography

William Scarfe

INTRODUCTION

Imaging provides the orthodontist with the means of visualizing, diagnosing and analyzing radiographic hard and soft tissue discrepancies of the craniofacial complex. Combined with clinical information, images provide the visual basis for planning the correction of three dimensional craniofacial malrelationships. Cephalometric imaging is also the primary clinical method involved in the prediction of craniofacial growth and the assessment of the results of treatment.

Radiographic images are a measure of the ability of various soft and hard tissue elements to attenuate an incident beam of ionizing electromagnetic radiation (EMR) called x-rays. The resultant alteration in the quality and quantity of the incident x-ray beam by the Compton or photoelectric effects is then recorded on photographic film as a latent image and by the process of developing, transformed into a visible image. This image spatially records differences in tissue density, type and thickness as differences in optical density on the film, visualized as variations in shades of grey. Images can now be produced which measure emission rather than transmission of EMR and include nuclear radioisotope scanning, spectral emission tomography (SPECT) and magnetic resonance imaging (MRI).

EXTRAORAL RADIOGRAPHY

Extraoral radiography plays an extremely important diagnostic role in the assessment of the osseous and soft tissue features of the orthodontic patient. However, a major limitation of orthodontic extraoral radiography is that only two dimensional static representations, usually in the antero-posterior plane, of three dimensional dynamic structures are produced. All images possess inherent distortions and inaccuracies, which are exaggerated by poor technique. Ideally, orthodontic imaging should accurately reproduce and relate both hard and soft tissue elements of the head and neck, demonstrate sequential change and aid in diagnosis of deformity with minimal patient risk or discomfort.

Cephalometric Radiography

Introduction

The use of cephalometric radiography in clinical orthodontics has contributed more to our assessment and understanding of craniofacial disorders than any other

single diagnostic tool. The cephalometric radiograph has become the basis for morphologic description, analysis, classification, growth forecasting and prediction of treatment results (Table I).

Table I - A Brief History of Orthodontic Radiography

Year	Development	Author	Description
1922	Roentgen ray anthropometry of the skull	Paccini	Radiographic measurements of external landmarks (dry skull)
1931	"Teleroentgenography"	Hofrath	Two plane system: 2 meter target-to-film distance & long lead tube.
1931	Broardbent-Bolton cephalometer	Broadbent	Head positioning device using ear rods, nasal rest and Frankfort horizontal. Two perpendicular x-ray tubes at 5 feet target distance with aluminum scale
1940	Adjustable x-ray cephalostat	Margolis	Uses conventional dental x-ray machine and adjustable cephalostat
1948	Laminography	Brader	Used Kelley-Koett medical equipment with 30 inch target film distance
1953	Cephalometric "Sectograph"	Ricketts	Upright body section apparatus of head initially produced (Now Denar/Quint)
1962	Cephalometric Cinefluorography	Sloan & Ricketts	Real time imaging of function movements of mandible, hyoid and throat
1974	Xeroradiography	Tipnis	Xeroradiography for lateral skull radiography
1974	Roentgen Stereophotogrammetric Analysis	Selvik et al.	Use of two x-ray tubes to produce coplanar stereo cephalometric image pairs
1978	Rare earth screens	Hurlburt	Comparison of faster screen film combinations in cephalometry
1983	X-ray Stereometry	Baumrind et al.	Development of a 3-D cephalometric method from paired coplanar images
1983	Three-dimensional cephalogram	Grayson et al.	Stereolocation of cephalometric landmarks from lateral & PA cephalograms
1985	3D CT cranial reconstruction	Marsh et al.	High resolution 3-D head and neck images
1985	Computed radiography	Koubayashi et al.	Photostimulable storage phosphors used in cephalometric radiography
1985	MRI	Katzberg	High resolution MRI of TMJ meniscus
1987	Dual screen cassette	O'Ryan & Croall	Use of dual intensifying screens in cephalometric cassette to enhance TMJ
1992	Linear array detector	McDavid et al.	Direct digital image acquisition by use of narrow fan beam and linear CCD array

Cephalometric Technique Considerations Equipment available

Three basic imaging systems are available for clinical cephalometric radiography, which vary according to the x-ray generator used and cephalostat configuration.

Medical X-ray generators are the most commonly employed for cephalometric radiography. The X-ray source is usually a pulsed or fully rectified alternating current (AC) generator with variable kV and multiple mAs settings. This allows a wide range of exposures and the possibility for the use of a grid technique. Focal spot size is usually in the order of 0.6 x 1.2 mm. The most commonly used cephalometric apparatus of this type (Wehmer Corporation, Franklin Park, IL, USA) allow a choice of x-ray tube head. The Quint Sectograph™ (Denar Corporation, Anaheim, CA, USA), provides a dual purpose apparatus combining tomography with cephalometric radiography. The major advantages of medical x-ray systems is that they allow the use of high mA and very short exposure times of approximately 0.1 to 0.2 sec. This procedure reduces the risk of patient movement during the exposure and therefore minimizes movement unsharpness.

A second option for the cephalometric apparatus involves the use of a conventional AC or direct current (DC) dental tube head as the x-ray generator at a fixed distance from a cephalostat. This requires the use of a fixator/collimator which positions the tube head for accurate alignment and collimates the primary x-ray beam. Because of the mA limitations of these machines, grid techniques are frequently not used and exposure times greatly increased and range from 0.6 to 1.5 sec. Despite the reduced financial cost, smaller focal spot size and utility of a dual purpose intra/extraoral system this is not a technique of choice in cephalometrics. Tube loading is greatly increased and the use of low kilovoltages increases subject contrast and image quality but decreases the range. Despite the limitations of some equipment, units capable of variable mA (10 or 15) and kVp (50 to 110), such as the GE 1000 (Gendex Corp, Des Plaines, IL, USA) are excellent for the purpose of cephalometric radiographs.

A number of manufacturers have made cephalometric attachments available to convert panoramic machines into dual purpose extraoral units. The x-ray generators may be either AC or DC and however are limited in their mA capacity. Object-to-source distance, kV range, time, and mA, and filtration as well as cephalostat features all vary between manufacturers (Table II). Soft tissue profile enhancement is usually post patient although some units provide pre-patient filtration. While these machines have the potential advantages of smaller focal spots (e.g. less penumbra) quantitative image clarity is slightly better with medical units such as the Sectograph™ (Wakoh *et al.*, 1993). This is probably due to the better screen response to increased x-ray beam energy resulting from the use of higher kV and greater total filtration. However, clinically this difference is probably diagnostically insignificant.

Filtration

The use of added filtration in cephalometrics removes longer wavelength, low energy photons from the x-ray beam (Taylor *et al.*, 1988). These photons are usually absorbed by the patient and do not contribute to the diagnostic image. While all x-ray generators are manufactured with built-in aluminium filtration, a number of materials have been suggested for use as supplemental filtration in cephalometrics including aluminium and rare earth materials. This filtration has an effect on the x-ray emission

Table II - Available Dual Purpose Panoramic/Cephalometric Equipment

Model Manufacturer	Generator Type	Magnif-ication	SOD (m)	kV	Cost*	Focal (mm)	mA	time (sec)	Features
PM 2002 CC Planmeca	DC	1.08-1.13	1.6-1.7	60-80	+++	.5 x .5	4 - 12	.2 - 3	Auto light alignment, variable FOD Aperture chart for filtration
Orthophos CD Siemens	DC	1.17-1.24	1.5	60-90	+++	.6 x .6	9 - 16	0.01-4.0	Tilting cephalostat allows other maxillofacial views. Adjustable pre-patient soft tissue filter. Nasal support, optical alignment
Orthoralix SD ceph Gendex	DC	1.1	1.5	60-80	+++	.5 x .5	4 - 14	.16-2.5	Nasal support, fixed FOD Pre-patient soft tissue filtration
Orthoceph OC 100 Instrumentarium	DC	1.08-1.14	1.6-1.72	57-85	+ + +	.5 x .5	12	.1-3.2	Nasal pointer, variable FOD, variable head positions. Magnification scale, pre-patient filtration
Cranex 3 Ceph Soredex	DC	1.13	1.7	63-81	++	.5 x .5	6 & 10	0.4 -3.2	LAT/OBL/PA options, adjustable prepatient filtration. Fixed FOD
Orthopantomo-graph (OPG) Orthoceph 10E Siemens	DC	1.17-1.24	1.5	60-90	++	.6 x .6	10	.5-3	Adjustable pre-patient soft tissue filter Fixed FOD distance, nasal support
X-Caliber CM Belmont	Pulsed AC	1.11	1.5	60-90	++	.5 x 1.0	10	.03-3.2	Visual alignment, variable FOD Post patient filtration, frontal head support, 2.6 mm Al
Rotograph 230 Plus Villa Sistemi Medicali	Pulsed AC	1.2	1.7	60-85	++	.5 x .5	10	.5-3.0	Fixed FOD distance, nasal & orbital pointer. Optional collimators/ cassettes with filters
Laser PC1000 Panoramic Corp	Pulsed AC	1.2-1.28	1.62	70-90	+	1.0 x 1.0	10	.4-5	Manual laser guided alignment of beam, post patient filtration Wehmer cephalostat - LAT/OBL/PA
Panoura - 10CSU Yoshida Kaycor	Self rectified AC	1.2-1.28	1.62	70-90	+	1.0 x 1.0	10	.4-5	LAT/OBL/PA options, 2.8 mm Al, variable FOD. Magnetized prepatient filtration wedges
Autopan 098CE Belmont	Pulsed AC	1.11	1.5	60-90	+	1.0 x 1.0	10	.3-3.0	Post patient filtration Older Belmont unit

LAT = Lateral cephalometric   PA = Postero-anterior   OBL = Oblique   SFD = Source-to-film distance
SOD = Source-to-object distance   FOD = Film-to-object distance   mm Al = millimeters Aluminium equivalent
Unless otherwise indicated LAT & PA projections only - Unless otherwise specified all units have 2.5 mm aluminium equivalent filtration - *: + = $10 - 15,000; ++ = $15 - 25,000; +++ = > $25,000 (US dollars)

spectrum similar to increasing kV and reducing mA. While these filters reduce surface exposure by up to 80% (Taylor *et al.*, 1988; Gilda and Maille, 1992), this is offset by an increase in scatter radiation and a necessity to increase exposure. Increased exposure however does not appreciably increase whole body radiation absorbed dose (H_e - see later). The use of a non rare earth filter, niobium (Niobi-X, Ken Jon Radiology, Inc. Austin TX, USA), also provides surface dose reductions of approximately 39%, however increases deep tissue exposure up to 30% . While the use of niobium diminishes sharpness, resolution and subject contrast, this does not appear to result in an appreciable loss in diagnostic image quality (Wakoh *et al.*, 1994).

Collimation

Collimation limits the field size of incident radiation to those areas of diagnostic interest. Collimation not only reduces patient somatic exposure but also exposure to the gonads by minimizing scatter radiation. Collimation also reduces the proportion of divergent x-ray beams, which contribute to image penumbra and scatter and therefore may contribute to image clarity. Cephalometric collimation provides images with higher contrast (Bankvall and Hakansson, 1982), in some cases with greater reliability of landmark location, and skin dose reductions of approximately 55% to 77%. While collimation to exclude the thyroid gland reduces thyroid dose by 40%, this is generally considered impractical. The use a thyroid collar, which reduces absorbed dose to the thyroid by as much as 90%, has been advocated (Taylor *et al.*, 1988).

Scattered Reduction

Although cephalometric radiography uses a standard focal spot-to-midsagittal plane, not all techniques use a standard object-to-film technique. While some techniques recommend placing the cassette as close to the patient as possible others propose a fixed distance from the mid-sagittal. These procedures result in an image with minimal magnification but reduces image contrast due to scattered radiation resulting in an image with minimal magnification. Two techniques have been proposed to reduce the amount of scattered radiation that arises from the interaction of the x-ray beam and the patient recorded by the cephalometric film.

The first technique involves the positioning of a metallic grid on the cassette. A grid comprises a meshwork of narrow lead foil strips arranged in a parallel pattern divided by an aluminium separation material. The lead strips function to absorb the non parallel latent image radiation including scattered radiation. While grid techniques produce cephalometric images with higher contrast, their use does not result in any improvement in the identification of cephalometric landmarks and require an increase in exposure of approximately 20% to 25% to produce optimal image density. This increase in exposure, combined with backscatter radiation from the grid, serves to increase patient exposure.

An alternative method to reduce scatter is to increase the distance between the patient and the cassette up to 15 cm. While this air gap technique results in a magnified image, it allows a portion of the scattered photons generated within the patient to be deflected away from the film, increasing image contrast and resulting in less exposure to the patient than the grid technique. In cephalometric radiography, an 9.5 cm air gap produces an increase in image magnification of approximately 7% with similar contrast and resolution compared to a grid. This technique reduces patient exposure by almost 60%, and although some cephalometric units have preset air gap distances, is the technique of choice to reduce scattered radiation.

Screens

Intensifying screens in the film cassette are used in cephalometrics to provide diagnostically acceptable images with reduced exposure (Figure 1).

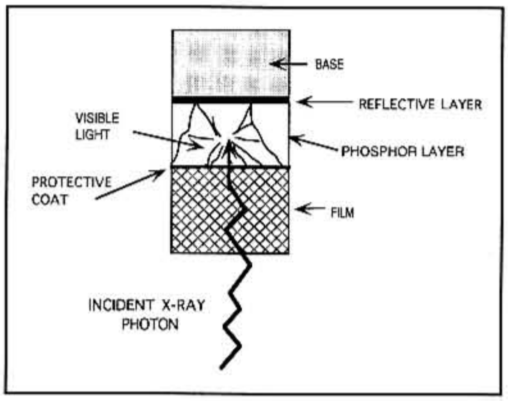

Fig. 1. Function of screens in extraoral radiography. Incident x-ray photons cause fluorescence of phosphor crystals. The visible light produced by this interaction may either 1) propagate in the direction of the x-ray photon, directly affect the silver halide crystals adjacent to the interaction, spatially recording and "intensifying" the effect of the x-ray photon, 2) propagate in the opposite direction of the x-ray photon and be reflected backward by the reflecting layer, or 3) propagate at an angle to the incident photon. Events 2) and 3) contribute to a loss in resolution and contrast of the image.

The introduction of rare earth compounds together with the spectral matching of films have resulted in faster speed systems and allow for a dramatic decrease (range: 66% to 96%) in the amount of radiation necessary to produce cephalometric radiographs (Taylor *et al.*, 1988). Clinically both image quality and cephalometric landmark location accuracy is similar to conventional calcium tungstate systems. The reduction in patient dose afforded by rare earth screens mandate the use of this system in cephalometric radiography. As screen/film speed and image quality are markedly affected by kilovoltage, a voltage potential around "80kVp" should be used to maximize the reductions in dose and optimize image clarity characteristics of these systems. A recently introduced screen cassette system incorporating dual sensitivity screens (TMJ Orthoceph Slimline Cassette System, Denar Corp., Anaheim, CA, USA) takes advantage of rare-earth phosphor technology by using intensifying screens of different speeds to produce images with greater subjective clarity in the TMJ region (Figure 2).

Fig. 2. Lateral cephalometric radiograph of a skull taken with the TMJ Orthoceph Slimline Cassette System (Denar Corp., Anaheim, CA, USA). This system uses intensifying screens of different speeds to produce images with greater subjective clarity in the TMJ region

Film

A number of film types are currently available, each designed to be matched with a spectral emission of cassette screens. Convention film (e.g. XRP, Eastman Kodak, Rochester, NY, USA) is sensitive to blue light and is therefore used in conjunction with calcium tungstate screens (e.g. X-Omatic), whereas orthochromatic film (e.g. Ortho G or Ortho L [Kodak] or Dentus ST series [Agfa Bayer AG, Dormagen, Belgium] and faster speed T-grain panchromatic film (e.g. T-Mat G or L [Kodak] or XD/A+ [3M Corp, Monrovia CA, USA]), sensitive to green and all color light respectively, is used with rare earth in-

tensifying screens (e.g. Lanex [Kodak] or Trimax [3M] series). Paradoxically, T-grain films have higher contrast and greater resolution than either Orthochromatic or conventional film. While T-grain films have a narrower latitude or usable exposure range, making them less forgiving of errors in exposure parameter selection, they permit more information to be perceived at lower exposures compared with conventional film. In general, the greatest resolution is achieved with the use of T-grain panchromatic film and medium screen combination. The use of Super HR film (Fuji Photo Film Co. Ltd., Kanagawa, Japan), a super fast, high sharpness film, shows potential for providing cephalometric radiographs of higher image quality with approximately 20% dose reduction compared with currently used rare earth screen combinations.

Film Processing

Film processing is one of the most technique sensitive factors in cephalometric film quality. Processing influences radiographic film contrast, defined as the difference in densities or variation in "blackness" existing between various regions on the film. In cephalometrics, a high contrast film that shows very light areas (e.g. TMJ) and very dark areas (e.g. soft tissue profile) is desirable. Film processing involves a two stage chemical process of developing and fixing which amplifies the latent image to form a visible pattern of silver (metallic). While it is important to follow the manufacturer's instructions in processing film, alteration of either the time or temperature of processing to suit the film/screen combination can maximize cephalometric film contrast. Processors may operate at lower than recommended temperatures (e.g. 31°C as compared to 35°C) or longer times with virtually no effects on overall density of the film. While this approach requires careful monitoring with densitometric equipment, image contrast can be greatly improved.

Soft Tissue Enhancement

There are basically two methods to enhance the soft tissue profile in cephalometric radiography. Pre-patient enhancement can be achieved by reducing the radiation intensity and quality before it passes through the patient by the use of pre-patient filters. Post-patient enhancement can occur by altering the aerial image before it is recorded using post patient filters or reducing the recording efficiency of the cassette in the anterior region using light absorbing dye or faster screens. While the use of pre-patient filtration is recommended as it reduces region radiation exposure to the patient, it does add to overall scattered radiation. Pre-patient filtration can be achieved by placing a selectively absorbing medium in the anterior portion of the x-ray beam. The use of aluminium, lead copper and more recently rare-earth intensifying screens as pre-patient filtration have resulted in skin entrance dose exposure reductions of approximately 25%, particularly to the anterior facial regions. This has improved visualization of the soft tissue profile and preserved appearance of the trabecular bone structure without reduction in diagnostic image quality.

Exposure Parameters

The selection of the correct exposure to produce an image with optimal density is based on a delicate balance of mA, time, collimation and grids with respect to the screen/film combination used. Contrast, the differentiation of the differences between two densities is determined by film and subject contrast, which is mostly determined by kilovoltage.

In cephalometric radiology two types of x-ray generator are available: alternating current (AC) or direct current (DC). In DC or constant potential systems, alternating current is transformed to constant potential current with high frequency. This allows continuous production and acceleration of electrons from the cathode to the anode, produces more photons and increases the mean energy of the photons in the x-ray beam, with less low level photons being produced. Kilovoltages used to produce x-ray photons in this system are indicated as kVcp as compared with kVp for AC generators. Because the x-ray beam has a greater proportion of high energy photons, shorter exposure cycles can be used. In addition, fewer of the lower kilovoltage (i.e. lower energy) x-ray photons are produced. This results in an x-ray beam delivering up to 30% less surface radiation to the patient and produces long scale contrast images with many shades of grey that demonstrate more information on tissue density. While theoretically higher kilovoltage beams are therefore better for producing images for skull cephalometry, this effect has not been found to be clinically significant. As absorbed dose decreases with increasing tube kilovoltage, particularly in the low kilovoltage range, kilovoltages less than 75 are not recommended.

Biological risks of cephalometric radiography

The use of radiation in dental diagnosis is always accompanied by some risk of biological damage. This concept is particularly important in orthodontics as patients are often children and adolescents and radiographic examinations may be repeated.

The energy of X-rays and their biological effects can be measured by a number of parameters including exposure, dose and effective dose equivalent. Individual and population radiation risks are reported as increased incidence of cancer induction.

Radiation exposure refers to the amount of radiation that comes out of the x-ray unit and reaches the person. The System International (SI) unit of exposure is the coulomb/kilogram (C/kg). The energy imparted from cephalometric radiography is dependent on a number of factors including tube voltage, filtration, mAs, focus-to-source distance, beam area at the film and generator type. Energy absorbed from cephalometric radiography varies from 20% to almost 50% less than panoramic radiography (Bankvall and Hakansson, 1982). Not all of the energy that a person is exposed to is actually absorbed by the body. The SI unit of dose is the gray (Gy). The absorbed dose to a patient in cephalometric radiography is dependent on the total energy imparted from the x-ray apparatus and varies with anatomic location and technique. Newer rare-earth screen systems allow significantly reduced doses. Higher tube voltages, added filtration and the use of anteriorly positioned wedge shaped aluminium filters lower surface exposure, however, result in higher doses to deeper tissues. The use of a lead neck collar and anterior soft tissue filter reduces thyroid dose by 90% and 30% respectively. For lateral, posterior and basilar cephalometric radiology maximum absorbed doses for specific radiobiologically sensitive sites are shown in Table III. These doses are approximately 20% to 50% less than comparative doses from panoramic radiography for specific organs.

The effective dose equivalent (H_E), is now the most widely accepted specification of the radiation dose to patients in dental radiology (International Commission on Radiation Protection, 1990). H_E is an estimate of the uniform whole-body dose carrying the same risk of stochastic effects as the dose administered to part of the body. In 1991,

the ICRP issued a new set of weighting factors for a total of 13 specific organs and tissues and renamed the quantity effective dose (H). In cephalometric radiography, the energy from irradiation is mainly imparted to the head, where the thyroid and a small component of the bone marrow (approximately 13%) is situated. This means that H_E results from 75-80% contribution from "remainder organs". Calculation of H_E for cephalometric radiography has not as yet been reported, however, should be in the order of approximately half of panoramic radiography or 3.8 µSv. This implies that H_E for cephalometric radiography is less than 5% of a full mouth series (FMS) and approximately 46% of a bite-wing examination. As H_E from annual background radiation is the order of 4,400 µSv (White, 1992), this means that a cephalometric radiograph is equivalent to about 6 hours of background radiation.

In an attempt to give these units some relative meaning, the potential biological damage can also be related to risk of the incidence of fatal cancer. Recent reports all recognize that the biological effects of low dose, low dose-rate exposure of low level radiation show a clear dose-rate effect (ICRP, 1990). These reports suggest that lifetime cancer risks from exposure to low levels of ionizing radiation may be greater than previously estimated. The risk of excess radiation-induced fatalities resulting from cephalometric radiography varies with respect to the critical organ involved, age and gender of the patient (Gilda and Maille, 1992). The probability of getting radiation-induced thyroid, salivary gland and brain cancer ranges from about 0.3 to 6 in one million, depending on technique, with the risk of thyroid cancer being greater for women than men. The comparative incidence rates for radiation induced cancer from panoramic radiography with rare-earth screens is 0.21 cases/million and approximately 2.5 cases/million for a FMS.

Radiation Protection

Because of these risks, a yearly safety limit for tissue exposure to ionizing radiation has been defined (ICRP, 1990). This is known as the maximum permissible dose (MPD) below which biological risks are considered minimal. The MPD for individuals working with radiation (i.e. occupationally exposed, including dental personnel) is 50 mSv, 10 times higher than the dose for "non occupationally exposed personnel" or occupationally exposed women "of child bearing capacity" (5 mSv). In the light of recent reports (National Research Council, 1990), MPD reduction to 2 mSv per year has been proposed for these individuals.

The ALARA (As Low As Reasonably Achievable) principle is now accepted practice to minimize these risks in dental radiology. Simply stated it means that every reasonable measure should be taken to assure that occupationally and non-occupationally exposed persons will receive the smallest amount of radiation possible. In cephalometric radiography this can be achieved by applying specific patient selection criteria and selecting techniques which reduce patient radiation exposure without loss in diagnostic information including the use of rare earth screens and beam filters, beam collimation, flat grained films, pre-patient soft tissue enhancement methods and the elimination of grids.

Advances in Cephalometric Radiography

Cephalometric analysis is subject to error from a number of sources including radiographic projection and measurement, and landmark identification. Therefore to increase inter and intra-rater reliability in landmark identification, reduce dose and standardize analysis, efforts have been directed towards the improvement of image quality by enhancing the radiographic image or the use of alternate radiographic sensors.

Digitization

Digitization of cephalometric radiographs involves the transformation of an analog film-based image to a digital code of binary numbers which are represented as different shades or levels of grey and visually displayed on a monitor. The cephalometric image may be directly transformed into a digital image via the use of a special sensors instead of film or indirectly from originally acquired cephalometric radiographs. A digital image is a representation of an object produced by creating a rectangular array of numbers representing grey values. The elements of this picture array are termed pixels. Each pixel may represent a number of different shades of grey or values dependent upon the number of components defining that pixel or bits. More bits per pixel means more levels of grey between black and white that can be represented and thus a finer grade of image is rendered. Generally an eight bit image, afforded by currently available personal computer technology is adequate for dental radiographic images (256 true levels). Computer processing routines can be used to perform mathematical operations on these numbers to enhance the image, or analyze dimensional data. Digital archiving devices such as laser disk or magneto-optical drives can be used for storage and retrieval and electronic transmission to a remote location is also possible.

Film-based or secondary cephalometric digital image acquisition can be achieved using a number of technologies including video cameras, linear diode array cameras, charged-couple devices (CCD), scanning microdensitometers or laser film scanners. The accuracy of bony landmark identification on cephalograms digitized by video camera produces equivocal results. While specific digital enhancement may not improve bony landmark identification, it may be superior in delineating soft tissue relationships. While this technique produces low cost images, limited resolution, field non-uniformities, distortions and peripheral loss of spatial resolution all contribute to image degradation. Alternate input devices such a flatbed scanners may improve image acquisition.

One application of digitized cephalometric imaging is the automation of landmarks. This process involves the use of a sophisticated computer program incorporating a detailed series of steps or algorithms in the identification of specific landmarks on a digitized cephalogram (Levy-Mandel *et al.*, 1986). Images are initially processed by the use of prefiltering to reduce background "noise" and edge enhancement before the program attempts to search for details on outlying contours and identify specific cephalometric points by the use of "operational" definitions. The implementation of smart computer programs to digital cephalograms reduces the inherent sources of human error in cephalometric analysis and improves the process of cephalometric measurement and analysis.

Alternate Sensors

Computed radiology (CR) involves the replacement of silver halide film with a re-usable receptor which provides a means of indirect radiographic digitization. The image receptor, called an imaging plate (IP) is a thin flexible reusable plate coated with a photostimulable phosphor compound in a cassette similar to that used in conventional extraoral radiography. With exposure to radiation, a latent image is produced by physical changes in the phosphor and is scanned by a narrow laser beam. The incident laser energy causes the phosphor to release stored energy in the form of luminescence (called photoluminescence) which is collected and amplified by a photomultiplier to produce electrical signals proportionately to the light energy produced. These signals are then converted

into a digital form and analyzed by an image processor. The final images are reconstructed and can be printed on single emulsion film.

Initial investigations indicate that CR may provide diagnostic cephalometric images with reductions in exposure (approximately 30% to 40%) without reducing operator reliability in landmark identification (Seki and Okano, 1993). The system is capable of producing images with better visualization of soft tissue structures and allows digital post processing contrast optimization to improve low quality images. Disadvantages include the high initial cost of equipment, increased time necessary to process images and the need for frequent technical assistance.

Recently efforts have been made to replace film with computer-based devices that use electronic x-ray detectors to record the aerial image. Direct digital acquisition of extraoral radiographs requires no chemical processing system and provides images for viewing almost instantaneously. A prototype system for direct digital cephalometric radiography developed by McDavid *et al.* combines a narrow beam scanning x-ray source collimated at the source and a linear scanning photodiode detector array (1992). During exposure the slit collimators and array traverse across the patient with the resulting image being displayed on a high resolution monitor. Magnification and resolution of the images produced by this prototype system vary in the horizontal and vertical dimensions but provide images adequate for cephalometric radiography (Figure 3). One of the advantages of this system is the excellent contrast of the image due to greatly reduced scatter radiation provided by pre and post patient collimation. Potentially higher quantum efficiency of electronic sensors in comparison to film should make possible a substantial reduction of x-ray dose to the patient.

Fig. 3. Digital cephalometric radiograph of a skull phantom produced with a prototype direct digital extraoral radiographic system. (Courtesy of Dr. William D. McDavid, University of Texas Health Science Center at San Antonio, TX).

3D Cephalometry

Accurate analysis of complex craniofacial anomalies with conventional two dimensional analysis is limited. The display of a 2D image three dimensionally can therefore provide greater diagnostic information and assist in treatment planning.

Essentially two systems for measuring three dimensional radiographic information are available. Both systems satisfy the requirements of x-ray photogrammetry by orienting the two radiographs, the projected points and defining the location of two x-ray sources with respect to a common coordinate system.

The Roentgen Stereophotgrammetric Analysis (RSA) system is based on biplanar geometry involving the 90° orientation of film cassettes to each other at the time or radiographic exposure (Selvik *et al.*, 1986). Two x-ray tubes simultaneously expose the patient, who is placed within one of two types of calibration cages used to define a coordinate system. Comprehensive computer software reconstructs the 3D patient coordinates. This technique has been applied to the study of cranial growth, bone segment motion after surgical orthodontic manipulation and craniofacial and neurocranial anomalies. It is highly sensitive to small changes over time and extremely accurate with maximal linear, angular and volumetric errors of 100 μm, 0.08°, and 0.05% respectively. This system was modified to incorporate submentovertex and lateral views (Grayson *et al.*, 1983) and developed to include the digitization of conventional lateral and posteroanterior cephalometric radiographs, called biplanar cephalometric stereoradiography (BCSR) (Trocme *et al.*, 1990) producing a spatially oriented wire frame representation or " 3D cephalogram". Although the linear measurement error associated with this technique is larger, in the order of 0.4 mm (Bookstein *et al.*, 1991) or 0.5% (Trocme *et al.*, 1990), this method is simpler to perform than the original coplanar method, involves lower radiation doses compared to CT and may have significant practical value for the quantitative evaluation of growth.

An alternative method of three dimensional reconstruction applies the principles of coplanar stereometry to cephalometry (Baumrind *et al.*, 1983). This method involves the production of a consecutive "stereo" pairs of lateral cephalometric images in the same plane taken at slightly different central beam angulations. The use of control arrays of radiopaque "points" whose projected images upon the film plane allow the retrospective calculation of the spatial relationship between the x-ray source and film plane. Film-based images may be viewed simultaneously or may be digitized and a three dimensional coordinate map constructed. Because images differ much less than those obtained orthogonally and because of the visual assimilation of information on both films, anatomic structures are easier to identify and errors in the location of anatomic landmarks reduced.

Non-radiographic cephalometric imaging systems

Non-radiographic systems are now available capable of providing images and diagnostic cephalometric analysis non-invasively and without risk of biological damage.

The simplest of these systems is the CCD based video camera which produces soft tissue images. With the application of various software applications (e.g. Truevision Image Processing (TIPS), AT&T or Orthographis, Mathematica Inc.) facilitating image modification, visualization of proposed soft tissue changes is possible, as well as cephalometric and soft tissue profile superimposition (Sarver and Johston, 1990). These systems enhance patient communication and assist in treatment planning in orthognathic cases and may potentially provide information on soft/hard tissue relationships.

The DigiGraph™ Work Station (Dolphin Imaging Systems, Valencia, CA, USA) uses a sonic digitizing system to produce a spatially oriented 3D cephalometric skeletal frame. The image is acquired by use of a sonic probe which emits a sound when placed on each facial or intra-oral cephalometric landmark to be recorded. This sound is recorded by a microphone array and processed to produce a three dimensional

x, y and z coordinate position for each superficial cephalometric landmark. Various software applications include 2-D analysis and 3-D cephalometric tracings, growth forecasts and visual treatment objective without radiation. Image manipulation is also possible allowing visualization of the effects of various treatment modalities. Additional features include the digitization and cephalometric analysis of conventional radiographs, a digital archiving capability, superimposition of tracings and integration of video images. The Dolphin system provides greater clinical accuracy of both angular and linear measurements from soft tissue landmarks than conventional film based methods however patient positioning difficulties and the inability to directly digitize many radiographic landmarks may limit the development of this system to soft tissue analyses (Chaconas *et al.*, 1990).

Rotational Panoramic Radiology

Panoramic radiology uses the principles of tomography, slit beam radiography and scanography to produce a single image of the facial structures, including the maxilla, mandible. The technique has many advantages including imaging a broad anatomic region, relatively low patient dose and ease of use. Unfortunately panoramic images lack sharpness and detail and demonstrate considerable image distortion and tooth overlap in certain areas.

The basic principle of the system involves the simultaneous rotational movement of the x-ray source and panoramic cassette/ film combination in opposite directions around the patient's head about an imaginary fulcrum . The x-ray beam is collimated into a narrow vertical slit which is projected at a slight angle (7-15^0) from behind the patient's head, through the skull and teeth to produce an image on the film. A moving, narrow collimating slit on the x-ray cassette side of the machine allows only a small amount of x-rays to strike the film inside and register an image at any one time. As the x-ray tube and film move, objects outside the tomographic "in focus" image layer are blurred. This configuration produces a three dimensional curved image layer encompassing the tooth bearing areas of the maxilla and mandible. The relationship between the x-ray source-film distance, rotational speed, beam width and film speed determine the size and shape of the image layer used to produce a relatively representative flat image of a curved object.

In orthodontics, panoramic radiographs are used almost extensively for diagnosis of dental and maxillofacial disease prior to orthodontic intervention including abnormal dental eruption patterns, impactions, cysts and neoplasms, congenitally missing teeth, premature teeth loss, prolonged tooth retention, abnormal dental resorption, dental ankylosis, fractures and space inadequacy. It also allows assessment of the longitudinal effect of interceptive or no treatment or the progress of surgical orthodontic treatment. During and post-treatment, the panoramic radiograph is used to evaluate root resorption, alveolar crest modification or root angulations of the teeth. In clinical practice, given that the patient is positioned within the image layer and that the jaw shape does not vary significantly from the average, panoramic images are basically reliable representations of object morphology. As long as the orthodontist is aware of inherent image limitations and is familiar with variations between systems then linear measurements using internal reference grids and mesiodistal angular measurements of buccal segments can be made with a 15% linear and ± 5^0 angular error respectively.

Advanced Imaging Modalities

Currently advanced imaging modalities are not routinely employed in the diagnostic phase of orthodontic assessment. These techniques are usually reserved for patients demonstrating specific indications as demonstrated clinically or by initial radiographic assessment using panoramic or plain film radiography.

Tomography

Tomography is used almost exclusively in orthodontics to visualize the temporomandibular joint (TMJ) of symptomatic patients. Because of the standardized projection geometry of the apparatus, the TMJ tomogram allows for a dimensionally accurate lateral or anterior-posterior view of the joint with minimal superimposition of adjacent structures. The tomogram is most useful for viewing static positions of the osseous elements of the TMJ in centric occlusion, at rest, and in an open position.

Tomography is a technique whereby an image of a designated coronal, sagittal or axial layer of discrete thickness within the head is produced while images of structures before and after that layer are made invisible by blurring. This blurring of structures outside the plane of interest is created by the simultaneous movement of the x-ray tube and film during exposure. The thickness of the image plane depends on the angle of rotation of the x-ray tube. More complex motions act to more effectively blur objects outside the focal plane and produce a clearer image but provide increased dose to the patient.

Ideal tomographic imaging requires multiple views of the condyles at various depths, usually at medial and lateral poles and centrally in rest position as well as central cuts at closed, rest and open position. Tomographs can demonstrate subtle and gross osseous changes of the glenoid fossa and mandibular condyle in degenerative joint disease as well as other TM arthropathies however false negative interpretations of these radiographs are common (Figure 4). Because of the inherent variability of condyle/glenoid fossa relationship in normal individuals and the effect of depth and angulation of tomographic slice on the image, the use of joint space as a diagnostic criterion in disc derangement is limited.

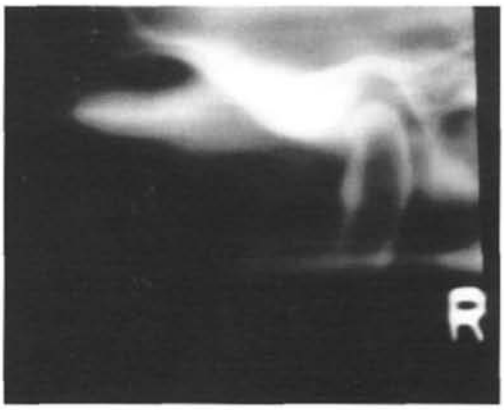

Fig. 4. Sagittally corrected linear tomograph of right TMJ (central cut) in the closed position with mild degenerative joint disease. Note the increase in glenoid fossa cortical sclerosis, pronounced slope of the articular eminence, sclerosis and anterior spur (osteophyte) formation of the condyle.

TMJ arthrography is an indirect method of visualizing the soft tissue elements of the joint space and has mostly been replaced by MRI as an imaging modality for patients presenting with suspected internal disc derangement. The technique involves the injection of a radiopaque contrast agent into either the lower joint space or both joint spaces and obtaining tomographic views. The technique is limited to patients likely to need surgery for disk repair or repositioning and should only be considered an alternative imaging modality if performed by experienced and competent radiologists or if nuclear magnetic facilities are unavailable.

Computed Tomography

Computed Tomography (CT) produces digital data measuring the amount of x-ray transmission through an object in three dimensions. The digital data can be matched to a density scale and a predetermined image layer is displayed on a TV monitor. This modality provides the clearest imaging of the hard tissues currently available.

Images are produced and acquired by positioning a patient within a CT scanner. This machine comprises a series of small x-ray tubes that generate fine beams that pass through and are recorded by interspaced crystal photodiode radiation detectors on the other side of the patient. The x-ray tubes fire, then rotate to a new position and fire again, until the subject has been scanned from all angles (Figure 5).

A computer keeps track of the intensity of all the readings from all the detectors as the beam rotates around the subject. The computer collates and combines this attenuation information into a three dimensional digital image matrix made of pixels. Each pixel represents the attenuation of the x-ray beam by a particular volume of material, as determined by the thickness of the scan slice as well as the resolution characteristics of the system. Each voxel is assigned a number, called a Hounsfield unit, proportional to it's tissue attenuation related to water. These numbers determine the brightness or CT number of the visual display (Figure 6). CT numbers range from + 1000 (dense bone) to -1000 (air) with water arbitrarily set at 0. The image is displayed on a CRT monitor. While CT numbers on an image can vary by as much as 2,000, the number of shades of grey

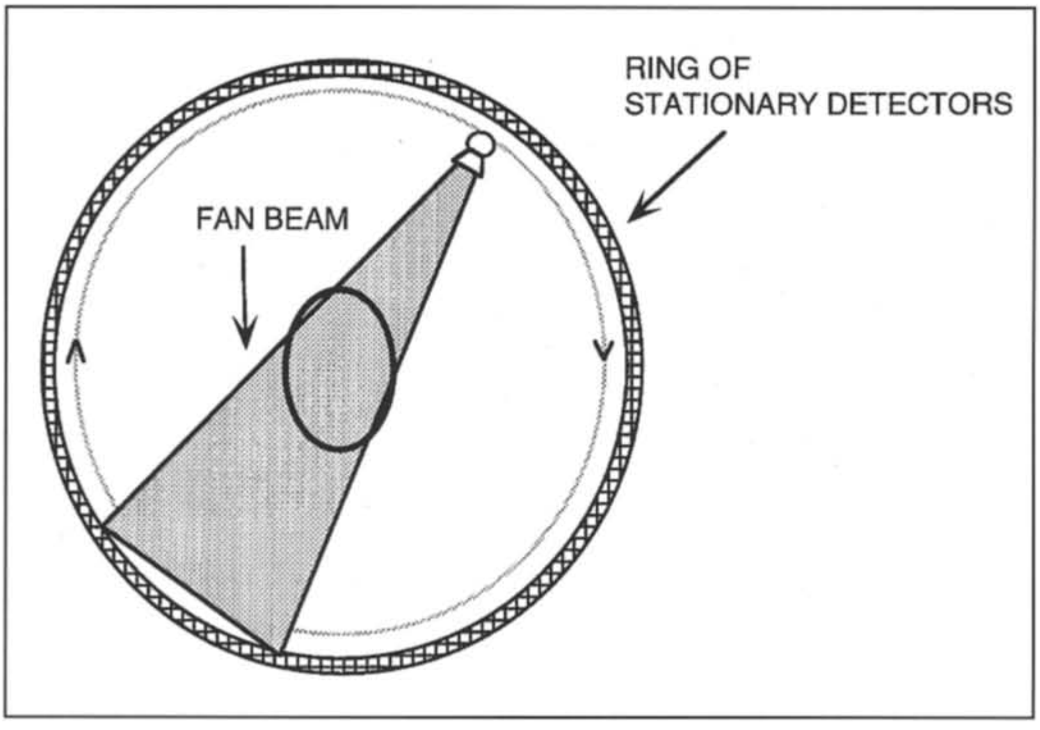

Fig. 5. Diagram illustrating the principal elements of a fourth generation CT scanner.

available to display the image is usually only 256. Therefore instead of showing a full range of CT numbers, a CT number is selected which is representative of the structure that is to be examined. This is known as the window level. The number of grey values above and below this can also be adjusted. This is known as window width. These two parameters can be adjusted to optimize either bone or soft tissue details from the scan. Scans are usually displayed in the manner in which they were originally acquired however two dimensional multiplanar (MPR) and three dimensional (3D) reformatting are also possible.

Spatial resolution of original CT scans is about 15 line pairs per centimeter, equivalent to approximately 0.3 mm. While this is not as good as conventional radiography, CT is far more sensitive in contrast resolution, capable of differentiating soft tissue densities of up to 0.5% as compared to 10% by film radiography. Because the minimum construction matrix (800 x 800) is usually greater than the pixel matrix of the monitor, the image is displayed by pixel averaging. While this reduces the resolution by two, it allows magnification of a portion of the image, called the area of interest (AOI) without loss in image quality. The major considerations in the use of this modality are cost and patient dose. Radiation dose averages 20 to 40 mSv depending on the equipment used and number of scans.

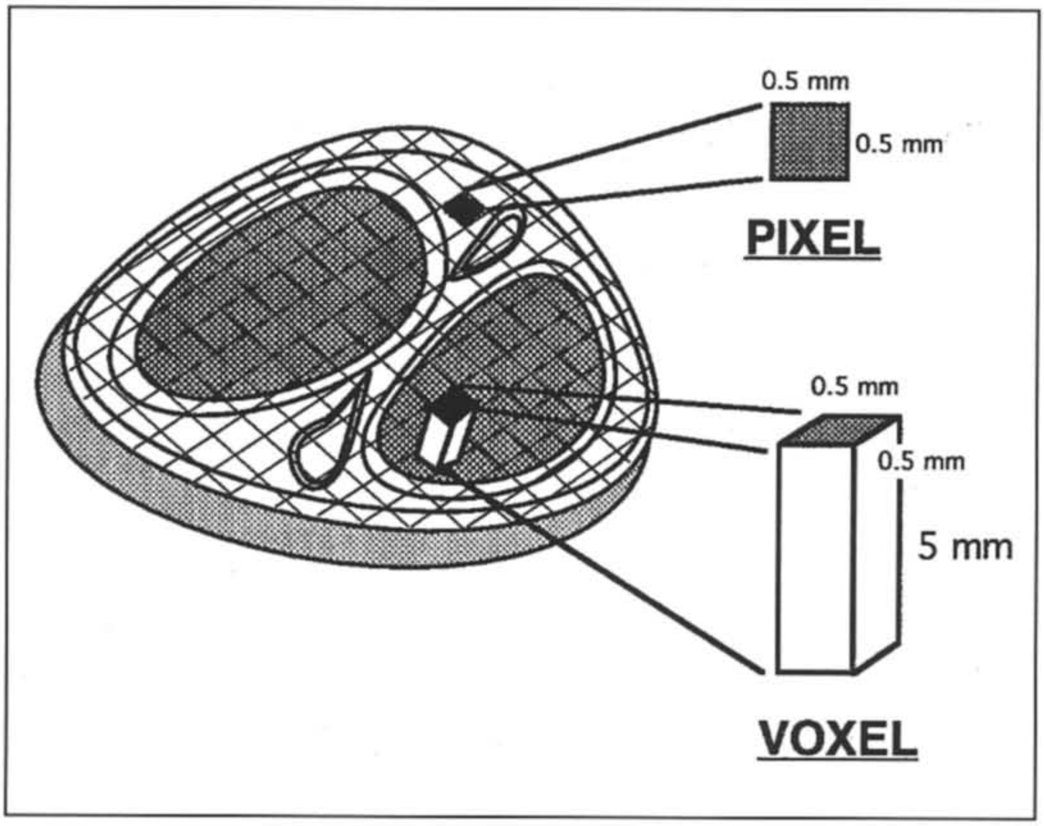

Fig. 6. Relationship of digital image picture element (pixel) to tissue volume element (voxel)

Fig. 7. Frontal (7a) and lateral (7b) 3D reformatted CT reconstructions of an 18 year old Hispanic patient demonstrating hemifacial microsomia (Goldenhar's Syndrome). (Courtesy of Dr. Marden Alder, University of Texas Health Science Center at San Antonio, TX).

CT is the modality of choice in the analysis of congenital, traumatic or genetic craniofacial anomalies and visualization of the osseous elements of the TMJ. Programs allow image enhancements including width windowing and leveling and can produce images from multiple perspectives including "panoramic" and disarticulation of osseous elements.

MPR or 3D reformatted images demonstrate a global view of the skull, require less mental assembly and are able to graphically demonstrate underlying bony deformity and soft tissue relationships (Figure 7).

While these images are capable of facilitating communication, direct linear and angular measurement of original, 2D and 3D images is possible. This allows the description, quantification and analysis of complex craniofacial anomalies (Marsh and Vannier, 1989). CT provides an accurate, reliable and reproducible representation of the head and neck region. In 3D, linear measurements appear to be more accurate than angular recordings while some landmarks remain difficult to identify (Hildebolt *et al.*, 1990). Recent orthodontic applications of 3D CT imaging include the establishment of normal values and growth trends (Waitzman *et al.*, 1992) and the analysis of craniofacial anomalies. The use of off-line work stations capable of computation based on multiple stereo images of 3D CT reconstructions offers the possibility of accurate measurement combined with consistent identification of osseous landmarks and is valuable where access to a CT scanner is limited (Brown and Abbott, 1989). The construction of "skeletograms" or wire frame models based on the digitization of points on a CT image using a mouse now allows personal computer based storage, retrieval and analysis of craniofacial bone anomalies (Ono *et al.*, 1992). Craniofacial procedures can also be aided by the use of three dimensional surgical simulation programs based on CT data linked to 3D data derived from biplanar

cephalometry providing interactive surgical modeling (Cutting *et al.*, 1986). Potential clinical cephalometric applications of CT data are now possible with the use of PC-based display, image enhancement and interactive software (e.g. Imagemaster-101™, Columbia Scientific Incorporated, Columbia, MD, USA).

Recently, two morphometric techniques for CT image analysis have evolved: Finite Element Scaling Analysis (FESA) (Brookstein, 1987) and Euclidean Distance Matrix Analysis (EDMA). While FESA and EDMA have been used to compare age and individual changes and to describe and quantify growth in facial dysmorphogenesis syndromes including Apert and Crouzons, more longitudinal studies are required to establish a normal database. Application of these analyses to CT imaging will provide the orthodontist with a better understanding of the nature and pathogenesis of major craniofacial anomalies and may potentially assist in the prediction of post treatment growth patterns.

Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) uses the property of the Nuclear Magnetic Resonance (NMR) of hydrogen nuclei in water following excitation by a radiowave to produce a computer derived picture of tissue. It is a non-invasive imaging technique as no ionizing radiation is used.

The application of a radio pulse to the spinning protons of atomic nuclei aligned under the influence of a strong magnetic field tips the axis of spin away from the magnetic field. As the nuclei return to alignment in the magnetic field, they produce a tiny radio signal of specific frequency for a brief time (Figure 8). This signal, detected by the coil, is recorded and located in three dimensions by the computer. By this method the location and percentage of hydrogen atoms within water (the most common element in the human body) can be determined and thus the composition of the tissue.

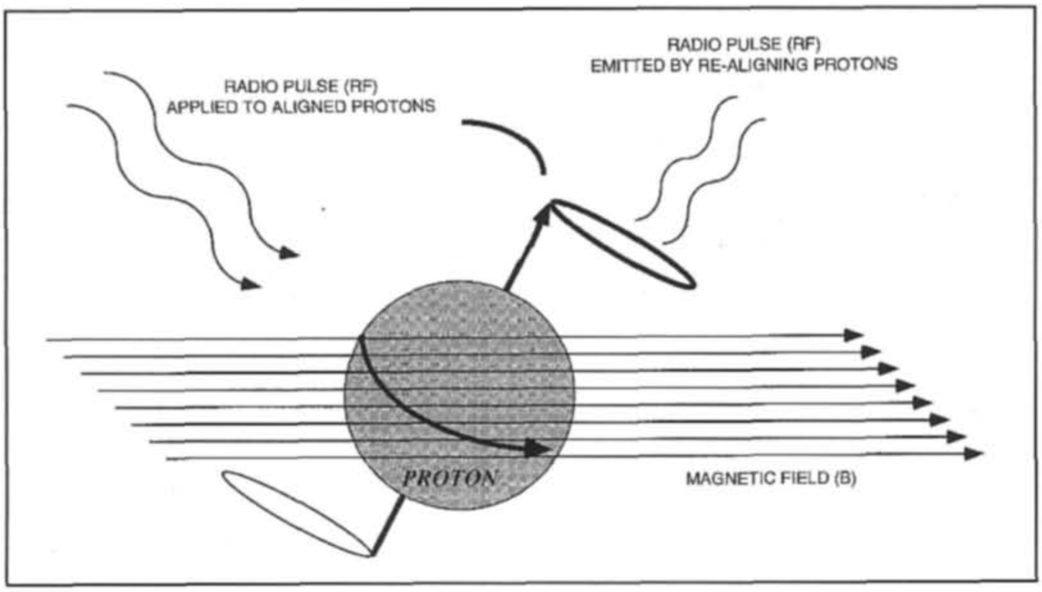

Fig. 8. Diagrammatic representation of production of Nuclear Magnetic Resonance. Cyclic application of a radio pulse to spinning protons in a strong magnetic field results in the production of a small radio pulse as the protons return to normal alignment.

The imaging system comprises a series of magnets which act synchronously to produce a strong external magnetic field, ranging from 0.3 to 2 T (tesla), "fine tune" field inhomogeneities and vary the magnetic field to localize emitted signals. Radio frequency (RF) coils, positioned either around or in the case of small structures, directly on the anatomic area of interest are used not only to excite nuclei within the patient but to receive RF radiation from the patient.

To a large extent, image contrast between tissues is determined by the RF energy transmitted (pulse sequence) and subsequently recorded from the patient. The most common pulse sequence used in MR imaging is spin-echo (SE). This technique involves directing a RF pulse at 90° to the patient to tip the aligned tissue magnetism into a different plane from which it can be measured. Variation of the repetition time (TR) of the RF and time taken to record the echo signal between RF bursts (TE) can produce three types of images (Figure 9).

Decreasing both TR (< 600 msec) and TE produces so called T_1 weighted or "fat" images. These images are optimal for anatomic detail such as the TMJ and fibrocartilage. Fat tissues in these images are shown as bright areas while lesions, CSF or bone appear darker (Figure 10a). Increasing both TR (> 2000 msec) and TE produces a so called T_2 or "water" image. These images are selected to identify the distribution of water and are better for identifying subtle tissue contrast as required with the assessment of neoplasia. CSF in these images are bright, while fat, appears darker (Figure 10b). Therefore both T_1 and T_2 contribute to the image of a particular tissue (Figure 9). The local chemical microenvironments of the hydrogen nuclei determine the tissue $T_1$and T2 relaxation times. Although another type of image with high levels of contrast can be produced with long TR (> 2000 msec) and short TE, so called proton density images, these often provide relatively little improvement compared to T_2 images.

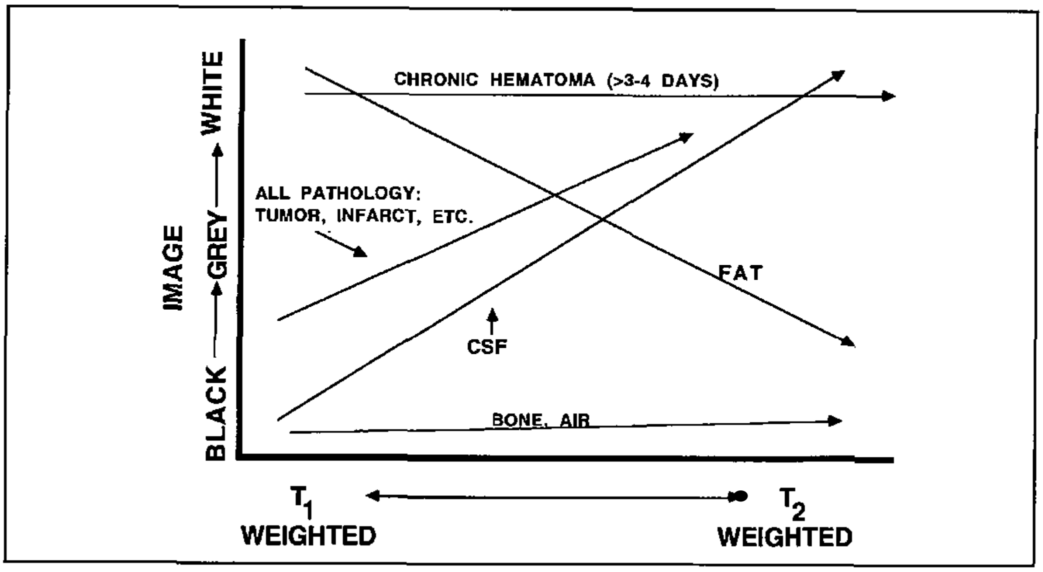

Fig. 9. Graph demonstrating the relationship between image contrast in the production of "water" and "fat" images and T_1 and T_2 weighting of NMR images.

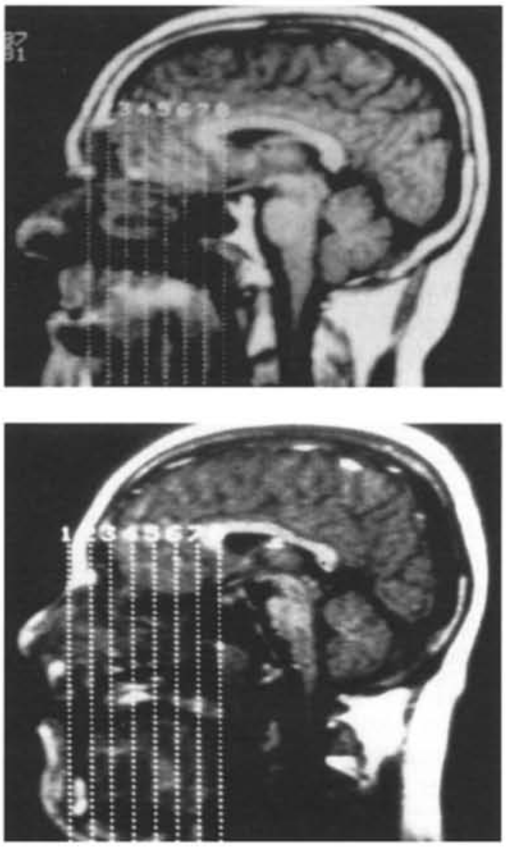

Fig. 10. Mid-sagittal MRI showing the differences in presentation and anatomic detail between T_1 (10a) and T_2 (10b) weighted images. Numbers indicate position of 2D reformatted coronal views.

MRI is very effective in detecting necrotic tissue, ischemia, malignancy and degenerative disease in soft tissue and produces better soft tissue contrast than x-rays or CT. Unfortunately, access to machines is limited, the service cost is high and time consuming and specific training is needed to interpret the images. With MRI, based on using hydrogen nuclei, teeth and bones, which contain relatively few hydrogen nuclei, are not well imaged. Both CT and normal x-rays image bone and teeth more accurately and with greater detail. However using imaging intensifying surface coils, small structures like the TMJ can be studied. As with other imaging modalities the standard plane of imaging the TMJ is in the sagittal plane. To image the joint, a dual surface coil technique for bilateral imaging is recommended which is time saving since both joints can be examined at the same time. Images are obtained in the sagittal plane with the mouth closed and opened and in the coronal plane with the mouth closed and open. This procedure demands the use of a bite block and is time consuming, with some patients experiencing facial muscle spasm. T_1-weighted images are the standard to delineate the anatomy. T_2 weighted images might be helpful for documenting fluid in the joint spaces.

While MRI is regarded as the optimal imaging modality in the assessment of internal derangement of the TMJ (Katzberg *et al.*, 1985), other orthodontic applications of this technology are emerging. MRI is now recommended for specific cases including orthognathic surgical correction of retrognathic deformities, evaluation of TM arthropathies, and assessment of patients with signs and symptoms of benign and malignant disease (e.g. salivary gland disease). Additional advances in the use of MRI include the possibility of functional TMJ studies using "Cine-MRI" (Quemar *et al.*, 1993), multiplanar imaging and three dimensional reconstruction of the TMJ (Price *et al.*, 1992).

Radionuclide Scanning

Potential application of bone scintigraphy in orthodontics exists in TMJ imaging. The technique has been shown to be a useful adjunctive modality in identifying subtle disk degenerative changes and internal derangement (Katzberg *et al.*, 1984) and in distinguishing TMJ disorders from other facial pain entities. The modality is not indicated for routine diagnosis of symptomatic joints. Bone scanning has particular application in

orthodontics in the assessment of condylar hyperplasia and continued growth post normal skeletal maturation.

Radionuclide or bone scanning using radiopharmaceuticals is most often used in medicine for the detection of malignant disease. Areas of increased activity are demonstrated by the preferential affinity and uptake of radio-isotope labeled compounds introduced into the blood system. Fluorescent screens within a gamma camera detects the radioactive emissions and convert these emissions into light photons and subsequently into electrical signals. The signals are reconstructed into an image which is displayed on a video monitor and recorded on photographic film. Areas of increased uptake appear more intense on the image. A well defined, localized area of uptake is referred to as a "hot spot". When bone function is to be studied (bone scan), 99mTc (technetium 99 metastable) is used. Radioactive 99mTc is a short half-life, radioactive gamma emitter which is bound to phosphate compounds that concentrate in actively metabolizing bone.

The images produced represent the biological activity of specific tissues under consideration. Although the modality is extremely sensitive it lacks specificity between activity due to inflammation or due to primary or metastatic tumor. The image is also very grainy and difficult to interpret. In the head and neck region, the modality has found application in the assessment of the viability of bone grafts, determining the extent and activity of locally aggressive bony and odontogenic lesions, in the assessment of systemic and metastatic disease and differentiation of inflammatory and neoplastic processes.

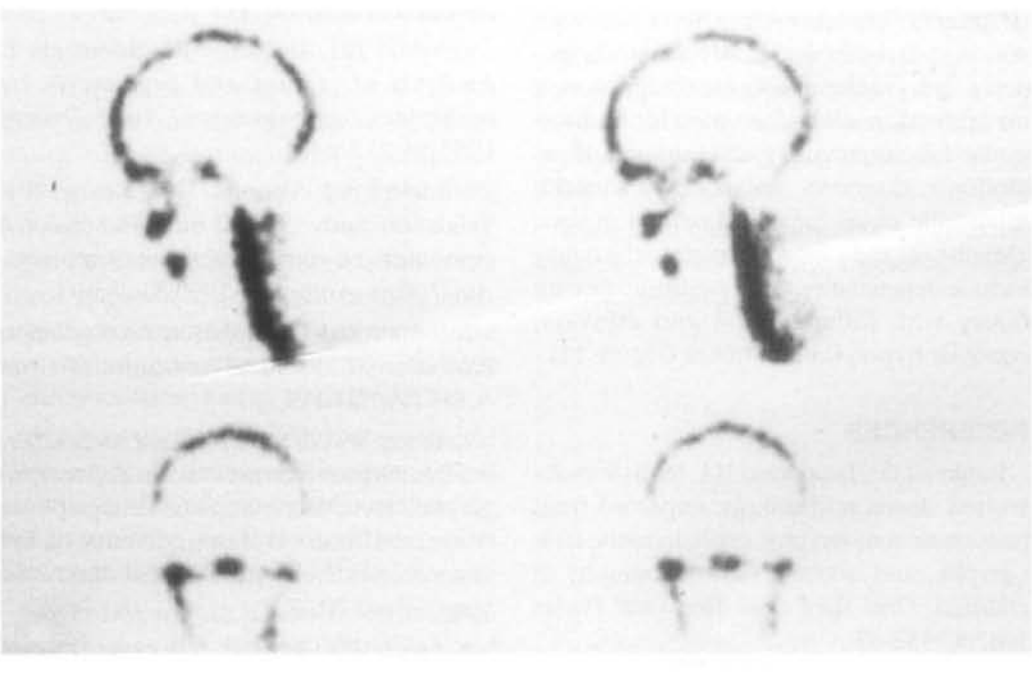

Fig. 11. Coronal and sagittal SPECT images (15 mCi Tc99m MDP) of a 14 year old female patient with unilateral asymmetry demonstrating moderately abnormal uptake within the right condyle consistent with condylar hyperplasia.

The use of tomography together with nuclide imaging, called single photon emission computed tomography (SPECT) is a valuable addition to bone scintigraphy. SPECT removes from the diagnostic image noise generated from unwanted activity in front and behind the tomographic plane of interest. The tomographic procedure provides images with greater contrast and anatomic clarity but reduced resolution. Abnormalities seen on planar bone scintigrams are often more convincingly identified and better localized. SPECT may even detect skeletal abnormalities not evident on planar views.

Emission tomography (SPECT) of the TMJ, although a sensitive and accurate measure of joint arthropathy, is rarely used in the diagnosis of facial pain or TMJ disorders. It not specific for a disease process and is less sensitive than MRI for the detection of TMJ derangement (Krasnow *et al.*, 1987). Although emission imaging is not advocated for patients with craniomandibular dysfunction, it may provide useful information for diagnostically difficult patients with symptoms. In orthodontic diagnosis, the modality is useful in specific cases for corroborating organic TMJ disease and joint arthropathy, which may include degenerative joint disease, acute joint injury with inflammation and effusion, condylar hyperplasia or tumor (Figure 11).

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6
Cephalometric Analysis

William C. Scarfe, John L. Schuler and Anibal M. Silveira

INTRODUCTION

Cephalometrics is the study of the osseous components and overlying soft tissue of the head by means of standardized radiographs. The tracings or cephalograms derived from these radiographs can be analyzed to describe a static situation at the commencement, during or after treatment. They cannot exactly identify aetiologies or direction of past or future growth. However, by comparing serial cephalograms of the same patient from different times, growth and development estimates are possible. Such comparisons are best made only if all cephalometric x-rays are taken under exactly the same conditions.

Development of The Cephalometer

Cephalometrics developed from Paccini's first anthropologic craniometric studies (Paccini, 1922). In 1924, Bolton added a metric scale to a head positioner, converting it to a craniometer, and measured a series of skulls to quantify dentofacial relationships. In 1929, Broadbent and Brodie first demonstrated the use of the radiographic cephalometer (Broadbent, 1931). This consisted of a head holder placed over a child's dental chair with rods inserted in the child's ear holes (external auditory meatus) to centre the head. A nose clamp and inferior orbital marker stabilized the head. The film cassette was held close to the left side of the head. Coincidentally, Hofrath (1931), working independently in Germany, described a similar technique for taking lateral head radiographs with a cephalometer but at a longer focus-to-film distance of two metres. Broadbent's more practical technique continues today as the most effective means of studying cranidfacial growth and dental position.

STANDARDIZATION

Cephalometric equipment

Modern cephalometric equipment consists of a cephalostat, or head holder, an X-ray source and a film holder to position the patient's head in a reproducable position perpendicular to the X-ray beam. To minimize image magnification due to the divergence of the beam from the X-ray source, a maximum source-to-object distance and minimum object-to-film distance is used. The X-ray source is located two meters from the mid-sagittal plane of the patient with the central ray of the X-ray beam directed at the

ear rods of the cephalostat. Australian and European convention positions the patient with the right side of the face nearest to the film. In the United States, Broadbent's original patient orientation is used, with the patient's left side of the face nearest the film and a 152.4cm (5 feet) source-to-object distance. Distance from the film to mid-sagittal plane can be held constant, usually 15 or 13cm, or the film may be positioned as close as possible to the patient's face, to minimize magnification. Specific machines may vary in this regard, hence, initial and final radiographs should all be taken on the same machine or they may lack accuracy with superimposition. To overcome this, radiographs may be taken with a millimetre ruler positioned at the mid-sagittal plane allowing calculation of a magnification factor. A cassette holder maintains film position at right angles to the X-ray beam and parallel to the patient's mid-sagittal plane.

Patient position

The patient should be in centric occlusion (CO) for each exposure. This stabilizes the mandibular position and allows assessment of the maxillo-mandibular relationship. If there is a large shift (>1-2mm) from centric relation (CR) to this position, the radiograph should be taken in centric relation with a wax bite holding the dental arches in this position. CO-CR discrepancy can also be taken into account if the pre-treatment models are mounted on an articulator in CR, with an appropriate facebow mounting.

All cephalostats currently use the external auditory meatus (EAM) to orient and stabilize the head at right angles to the x-ray source with respect to axial and sagittal head position. This assumes that the trans-meatal axis is perpendicular to the midsaggital plane. However, using the EAM for orientation can cause inaccuracies. If the patient's ears are asymmetrical, head tilt results, causing widely separated bilateral structures which may mimic the appearance of a patient with an asymmetrical maxilla or mandible. Common sense must prevail when positioning - having no head tilt is much more important than having the rods in the patients ears.

Frankfort Horizontal (FH) should be parallel to the floor. The ear rods should be firmly in the ears, and the patient's head slightly suspended. A nasal rest provides three point fixation. The head is placed with the patient looking forward, in a "natural head position". A proposed positioning convention integrates frontal with lateral radiographs, by positioning the canthus of the eye 15mm above the level of the ear rods (Rocky Mountain Data Systems).

Soft tissue visualization may be achieved by an aluminium attenuating shield either incorporated into the cassette, held by the patient or positioned at the X-ray aperture. While most practitioners prefer the lips in the rest position, some prefer the lips forced closed, particularly if there is a protrusive tendency, to visualize the mentalis muscle activity.

Natural head position

Natural head position (NHP), is now established as the most appropriate reference position for cephalometric radiography (Moorrees and Kean, 1958, Lundstrom *et al.*, 1991; Lundstrom and Lundstrom, 1992). It is a postural position which an individual adopts in everyday stance, where the pupils of the eyes are centered and the individual looks straight forward, defining the line of vision or true horizontal (TH). This imaginary line should be parallel to the floor when cephalometric radiographs are taken. The reproducibility of NHP is within the clinically acceptable range of 4° (Siersbaek-Nielsen and Solow, 1982), which is substantially less

than the variability of FH and Sella-Nasion (SN) plane among different individuals (Moorrees and Kean, 1958).

There are two basic approaches to determining natural head position:

Self balance

Molhave (1958) defined "orthoposition" as the posture assumed by the head from a standing to a walking position, achieved by letting the patient take a step forward. Siersbaek-Nielsen and Solow (1982) described an alternate method of allowing the patient to tilt their head backward and forward with decreasing amplitude until finding a neutral position, similar to performing a "yes" motion with the head.

Fixed object reference

This position is determined by the patient looking at an object in the distance - on the horizon or into their own eyes in a mirror or by measuring the height of the pupils from the floor and placing a dot on the wall at that height.

Solow and Tallgren (1971) found that there is about a 3° difference between natural head position obtained with both techniques. The self balance approach was more variable than the fixed object reference position (2.48° vs. 1.43°). Showfety *et al.*, (1983) described a radiopaque, fluid filled head level which he used to reproduce natural head position without the interference from ear rods and nasion rests. Fricker (1988) also describes a head stabilizer arrangement for NHP using bilateral projected grids and avoiding ear rods.

The major disadvantage of using NHP is that not only is it technically demanding, but also position is affected by many factors including the presence of ear rods, error in positioning of the cephalostat, airway adequacy and previous traumatic head and neck injury.

Some analyses are based on NHP (Cooke and Wei, 1988; Viazis, 1991). The overriding assumption in these analyses is that FH is parallel to NHP. Downs used a true horizontal plane in conjunction with the norms based on FH (Downs, 1948). This concept can be applied to current techniques by taking radiographs in NHP, basing the measurements on the true horizontal, and comparing them to the means and standard deviations of the Bolton and Michigan standards. If this tenet is accepted, all analyses based on the NHP line as a reference can be used, provided the difference between FH and NHP horizontal is less than 1° to 2°.

Film orientation

Many practitioners prefer the cassette positioned horizontally while others prefer a vertical position to visualize the cervical spine. The second technique results in a direct increase in radiation exposure to the thyroid in growing children and some degree of image magnification, as the film usually needs to be positioned further away from the patient to accommodate the shoulders. Advocates of this technique believe that the additional diagnostic information more than compensates for the greater risk associated with exposure of the neck region.

CEPHALOMETRIC PROJECTIONS

Types

Three standardized radiographic projections are used in cephalometrics; including the lateral, posterior-anterior and axial radiographs.

While most commonly used for sagittal orthodontic evaluation, the lateral cephalometric radiograph is also useful for assessment of fractures involving the maxilla or cervical spine, the maxillary

sinuses, localization of foreign bodies and anomalies involving sella turcica enlargement such as pituitary adenoma or craniopharyngioma. The radiograph is taken such that the central ray of the X-ray beam is directed toward the external auditory meatus, perpendicular to both the midsagittal and film planes and enters 2cm above and 2cm anterior to the external auditory meatus.

The posterior-anterior projection provides a general appreciation of the symmetry of the skull coronally, visualizes the lateral wall of the maxillary sinus, nasal septum, supra and infraorbital ridges, external auditory meatus and the remaining sinuses. Positioning involves centering the head in front of the cassette with the tragarcanthal line parallel to the floor with the forehead and the nose touching the film. The central ray of the X-ray beam, which should be in the mid-sagittal plane of the head at the level of the bridge of the nose, enters external occipital protuberance and exits nasion.

The axial projection, also called the "jug handle", submentovertex (SMV) or basilar view, provides a general appreciation of the symmetry of the skull, especially that of the mandible, the zygomatic arches and all sinuses. It aids in determining the medial or lateral position of foreign bodies and is useful in assessment of foramina at the base of the skull including foramen ovale, spinosum and magnum. The patient's head and neck are hyperextended backward as far as possible with the mid-sagittal plane perpendicular to the floor, and the vertex of the skull placed on the centre of the cassette. The centre of the X-ray beam is directed from beneath the chin to the vertex of the skull with it entering the midline between the condyles.

Geometric considerations

Enlargement and distortion due to projection geometry account for a number of considerations in cephalometric image interpretation.

Enlargement is inherent in all images due to the divergence of the X-ray beam from a point of focus. Magnification depends on the target-object and object-film distance. Manufacturer specific magnification factors apply to midsagittal structures. Structures on the right side of the face may only be 6-8% enlarged compared to those on the left side which may be magnified up to 14%. Thus, it is normal to see bilateral structures, such as the lower border of the mandible, posterior border of the ramus and inferior orbital rim, not superimposed over one another.

Film features

In a correctly positioned symmetrical mandible, the lower border of the right side is superior to the left. The posterior border of the right ascending ramus is normally distal to the left ramus. Differences between right and left images of more than 5mm should be checked for head positioning error. Transverse head rotation is evaluated by comparing horizontal relations of right and left orbital rims. Lateral head tipping is verified by comparing vertical differences between right and left images. Bilateral images often compared include: the posterior areas of the occlusal plane, the orbital rims, and the sigmoid notches of the mandible.

To identify potential errors due to inaccurate position of the EAM, the lateral radiograph should be compared to frontal or panoramic films to verify right and left ramus heights. The SMV radiograph can also be used to check the horizontal mandibular corpus length for asymmetry. It is critical to

determine left from right structures in order to draw conclusions regarding treatment effects, symmetry, eruption, etc. When two images present, these structures may be represented by the structure closest the film or a solid line being an average of right and left (Broadbent, 1975). Whatever convention is adopted, consistency is important for serial comparison of images.

CEPHALOMETRIC ANATOMY

Tracing technique

Most cephalometric analyses are made from acetate tracings positioned over the radiograph, which allows superimposing successive tracings for analysis of growth or treatment effects. For the American Board of Orthodontics (ABO, 1992), superimpositions are sequentially colour coded: BLACK - the original untreated tracing; BLUE - interim or intermediate tracing; RED - the first post-treatment tracing and; GREEN - two or more years out of treatment.

For normal bilateral structures, both images are mentally averaged, and a single outline is traced. If there is special interest in bilateral structures, or an unusually wide bilateral discrepancy exist, both structures should be individually traced. Tracing materials include: a view box; 0.003" thick frosted acetate tracing film; sharp 2H or 3H pencils; transparent orthodontic protractor and millimeter ruler; tooth template and; clear acetate tape. The acetate tracing film can be adhered to the film by two strips of tape. Three reference marks (e.g. X) should be positioned at three corners the film at right angles to each other to form the apices of a triangle. Tracings are best done in a darkened room, with extraneous areas of the light box and cephalometric film covered with black paper to minimize glare.

Errors

Errors in radiographic projection and cephalometric tracing techniques account for misrepresentation of the skull radiographically.

Projection errors can occur with alterations in patient relationship with respect to the X-ray tube and the cassette and are usually due to poor positioning within the cephalostat. They present as major discrepancies in the representation of bilateral structures such as the lower border of the mandible or planes of occlusion. Tracing errors may be caused by the lack of clarity of cephalometric landmarks due to superimposition of structures, blurring of the image brought about by movement during exposure, lack of film contrast and emulsion grain. Measurement errors due to the thickness of the pencil line and perceptive limits of the human eye also contribute to tracing errors. Measurement errors due to inter and intraobserver variability also account for a significant source of error. A number of generalizations can be made:

1) The larger the distance between cephalometric points, the less error in angular measurements;
2) Errors in the plane of the measurement have less impact than errors outside of the plane of the measurement;
3) Some anatomical points are intrinsically very difficult to locate such as Porion, the apices of the incisors and the condyle;
4) Soft tissue angles are less reliable than hard tissue angles;
5) Projection errors will always increase an angle if rotated about a vertical axis and decrease if rotated about a horizontal axis and;

6) Inter-observer error is a greater source of tracing variability than intra-operator error.

Because of the inherent errors possible in cephalometric tracing, one measurement should never be relied upon solely to determine treatment. Cephalometric measurements are a loose guide, not designed for rigid treatment planning.

Cephalometric Osteology

Accurate interpretation of sagittal cephalometric images demands a thorough knowledge of skull osteology, and requires a meticulous and systematic approach to the identification of structures of the cranial base, facial bones, dentition and soft tissue on cephalometric images. The following provides the practitioner with a guide for tracing the important structures on lateral cephalometric radiographs (Figure 1). Structures in the posterior-anterior projection are identified in Figure 2.

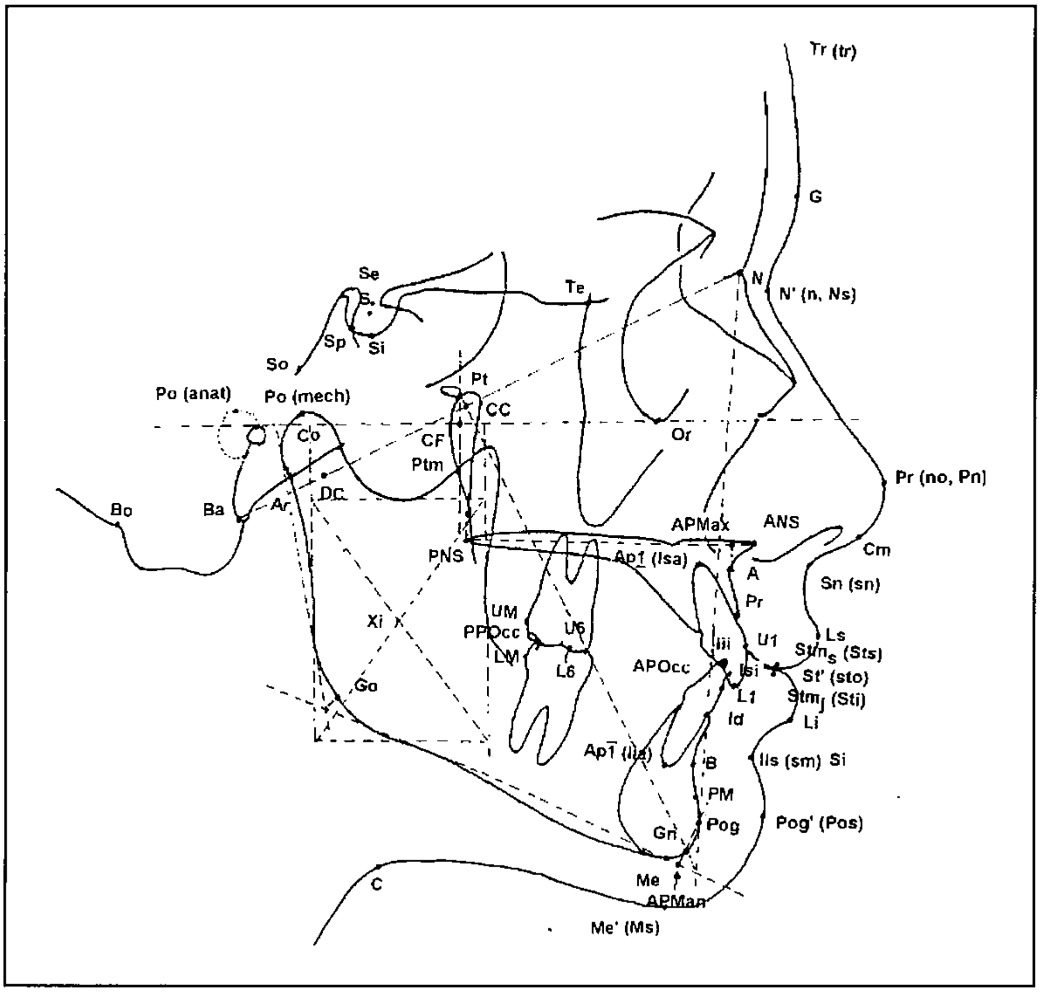


Fig. 1. Lateral cephalometric structures and landmarks of the craniofacial skeleton and soft tissue profile.

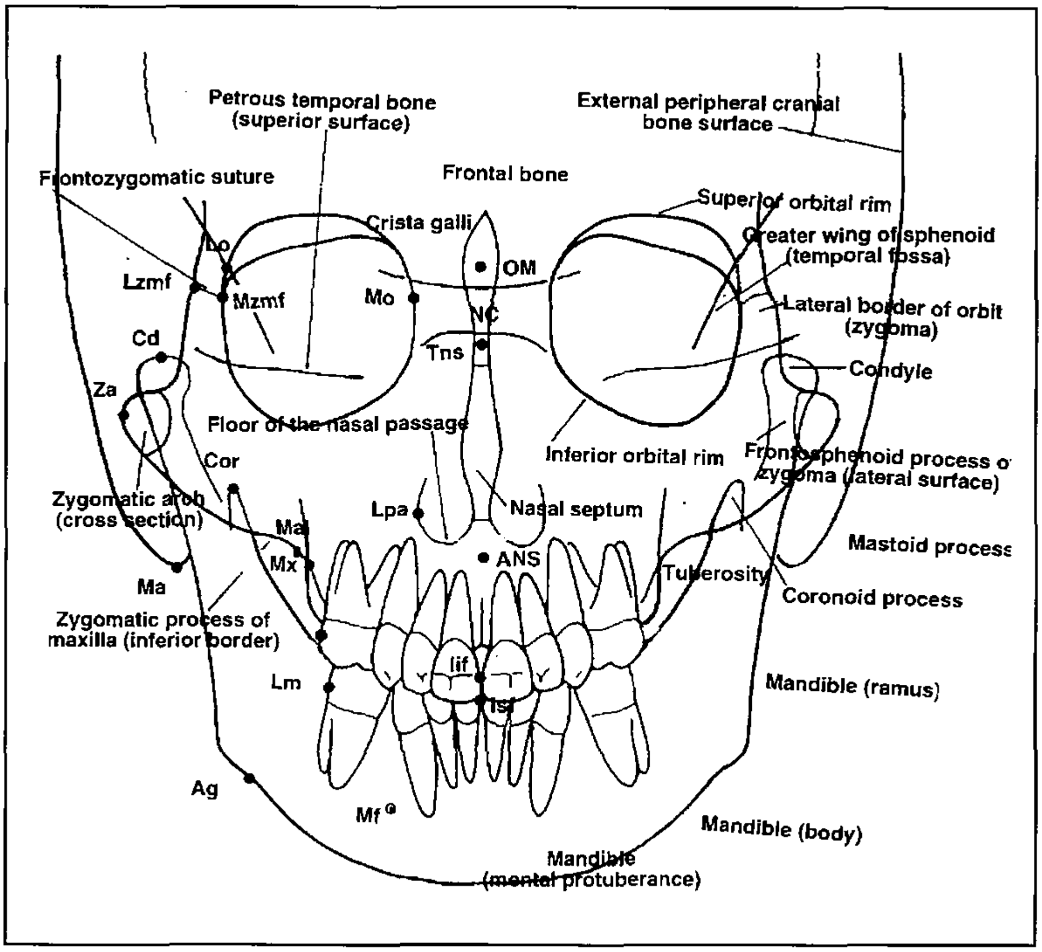


Fig. 2. Structures to be included in the tracing of a posteroanterior cephalogram. The most commonly used landmarks are identified on the right side of the tracing.

Cranial base

The centre of the cranial base is the Sella turcica or "Turkish saddle" shaped pituitary fossa of the sphenoid. The posterior border of this structure, the posterior clinoid process, extends posteriorly and inferiorly, becoming the basilar portion of the occipital bone and terminating at the foramen magnum. The anterior border of Sella, the anterior clinoid process, extends anterior superiorly to split into two main radiopaque lines; a horizontal line representing the planum of the sphenoid which anteriorly becomes the ethmoid and: an oblique line composed of the lesser wings of the sphenoid and roof of the orbits. Both are bisected by the anterior borders of the two greater wings of the sphenoid. The junction of the external plate of the frontal bone and the superior extent of the nasal bone, known as the frontonasal suture, seen as a notch or line is used as an important reference point (Nasion). The average outline of the two orbits completes the first phase of tracing.

Maxilla

The pterygomaxillary fossa (PTM), which forms an inverted tear-drop, located above and posterior to the posterior nasal spine of the hard palate is the next structure to be identified. The anterior contour represents the maxillary tuberosity, while the posterior contour, the pterygoid plates of the sphenoid. Bilateral PTM's should be mentally averaged into a single tracing. Next, the posterior vertical and inferior curvatures of the left and right zygomatic bones should be identified and their averaged position drawn. Finally, the maxilla is drawn by first tracing the nasal floor (a horizontal line connecting the anterior [ANS] and posterior nasal spines [PNS]). PNS is often masked by unerupted molars, but horizontally is located adjacent to PTM. Then the anterior-inferior contour between ANS and the alveolar junction at the maxillary incisors is drawn. Excluding the teeth in this region, the tracing continues posteriorly to form the palatal surface of the anterior alveolar process and roof of the mouth. Internal distinct trabecular patterns in the anterior half of the body of the maxilla are of considerable value in superimposition. Distinct markings such as the incisive canal may also be traced.

Mandible

The first structure to be identified is the symphysis, located exactly in midsagittal plane followed by the left and right outlines of the mandibular body. Below the bicuspids, the border has a convex shape, becoming more concave progressing towards the angle of the mandible. Both sides should be averaged to produce a single line unless special interest in each image exists. This follows on to become the respective posterior borders of the ramus which intersect the base of the occipital bone. The head of the condyle is usually obscured and should be drawn only when it can be seen clearly. If condylar position is estimated, it should be drawn as a broken line.

Dentition

Two pairs of teeth represent the dentition: the first permanent molars and the central incisors. Because of overlap and superimposition, it may be difficult to distinguish between right and left teeth, however, plaster models, a concurrent panoramic radiograph and restoration can be helpful in this determination. Plastic templates are often used to assist in outlining the dentition. In this case the entire template is seldom used, moreover sections of the template are employed to assist in producing smooth regular outlines. The most anterior upper and lower incisors should be identified and drawn including the entire crowns and roots. The average contact between the left and right proximal contacts of the molars should be used to align the drawing of a single molar.

Soft tissue profile

The entire soft tissue profile from forehead to chin should be identified and drawn. Pharyngeal structures which should be noted include the posterior pharyngeal wall (for adenoid and turbinates enlargement), inferior turbinates (if enlarged may extend posteriorly beyond PTM), soft palate (contacts dorsum of tongue unless enlarged tonsils are present or a history of mouth breathing reported), and tongue (posture verified by position of hyoid bone: normal level is between C3 and C4).

Landmarks

The basis of analytical cephalometrics are the landmarks chosen from which linear and angular measurements are made. Landmarks may be either midsagittal, bilateral or constructed geometrically. The most commonly used landmarks are defined in Table 1.

Figure 1 shows the most important sagittal landmarks. Some hard tissue points have corresponding soft tissue landmarks which are designated by a prime (e.g. Pog').

Planes And Lines

A number of planes or lines are able to be constructed using permutations of the above cephalometric points. The most common planes, together with their definitions are shown in Table 2.

Table 1. Definition of cephalometric reference landmarks

Lateral Skeletal Landmarks		
A	A Point, ss, subspinale	Signifies the apical base or the juncture of maxillary basal bone with alveolar bone. Lies anterior to the upper central incisor apex and is the deepest midline point in the curved bony outline from the base to the alveolar process of the maxilla, i.e. at the deepest point between the anterior nasal spine and prosthion.
ANS	Anterior nasal spine, sp, spinal point	The tip of the spinous process of the maxilla forming the most anterior projection of the floor of the nasal cavity in the midsagittal plane.
APMan	APMan	The anterior landmark for determining the length of the mandible, defined as the perpendicular drawn from Pog to the mandibular plane.
APMax	APMax	The anterior landmark for determining the length of the maxilla. It is constructed by drawing a perpendicular from A point to the palatal plane.
Ar	Articulare	The point of intersection of the inferior surface of the cranial base and the averaged posterior margin of the border of the ascending ramus.
B	B Point, sm, supramentale	Signifies the apical base or the juncture of mandibular basal bone with alveolar bone. Lies near the apex of the lower incisor, the most posterior point between Pog and the crest ot the labial plate.
Ba	Basion	The lowest point on the anterior medial margin of the foramen magnum in the midsagittal plane.
Bo	Bolton point	The intersection of the occipital condyle and the out line of the foramen magnum; the deepest point of the curve posterior to the occipital condyle which lies on the articular surface of the atlas.
CC	Centre of cranium	The point of intersection between the BaN plane and the Facial Axis (PtGN) plane.

Lateral Skeletal Landmarks Cont'd		
CF	Centre of face	The point of intersection between the Pterygoid vertical and Frankfort horizontal.
Co	Condylion, Cd	The most posterior and superior point on the out line of the mandibular condyle
DC	Dead centre (of the condyle)	A point selected in the centre of the condyle neck on the BN plane.
Gn	Gnathion	The most anterior - inferior point on the contour of the bony chin. Constructed (Ricketts) by bisecting the angle formed by the mandibular plane and the facial plane. Also defined as the lowest point of the chin and therefore synonomous with Menton.
Go	Gonion	The centre of the inferior contour of the angle of the mandible or the most posterior and inferior point on the angle of the mandible. Formed by the junction of ramus with the lower border of the mandibular body on its posterior inferior aspect. Constructed (Ricketts) by identifying the intersection of the bisector of the mandibular plane angle and the plane of the posterior border of the ramus (a plane tangent to the posterior of the ramus at both the condyle head and the angle of the mandible) with the lower border of the mandible.
Id	Infradentale	The alveolar rim of the mandible; the highest, most anterior point on the alveolar process, in the midsagittal plane, between the mandibular central incisors
Me	Menton	The most inferior point on the outline of the man dibular symphysis in the midsagittal plane.
N	Nasion	The most anterior point of the junction of the frintal and nasal bones (nasofrontal suture).
O	Point O	The intersection or point of convergence of the parallel to supraorbital line, the palatal plane, occlusal plane and mandibular plane
Or	Orbitale	The lowest point on the averaged inferior borders of the bony orbits.
Pm	Protuberance menti	The point on the anterior border of the chin where alveolar bone changes to basal bone. Represents the anterior limit of the apical base because it does not change with treatment (Ricketts).

Lateral Skeletal Landmarks Cont'd		
Pog	Pogonion	The most anterior point on the symphysis of the mandible in the midsagittal plane, the bony chin prominence.
Po	Porion (Anat)/ (Mech)	Anatomic porion is the midpoint of the upper contour of the external auditiory meatus. Mechanical or machine porion is the midpoint of the upper contour of the metal ear rod of the cephalostat.
PNS	Posterior nasal spine, Spinal nasalis posterior	The most posterior point on the spine of the palatine bone of the hard palate. Constructed midsagittal radiological point by the intersection of a continuation of the anterior wall of the pterygopalatine fossa and the floor of the nose.
Pr	Prosthion, superior prosthion	The alveolar rim of the maxilla: the lowest, most anterior point on the alveolar portion of the premaxilla, in the midsagittal plane, between the maxillary central incisors.
Pt	Pterygomaxillary point	The junciton of the ptergygopalatine fossae and foramen rotundum located at the posterior-superior border of the averaged pterygopalatine fossae.
Ptm	Ptergomaxillary fissure	The contour of an oval, tear-drop shaped radiolucency resulting from the fissure between the anterior margin of the pterygoid process of the spehenoid bone and the outline of the posterior surface of the maxilla.
S	Sella , Sella Turcica	The centre of the pituitary or hypophyseal cavity. Literally the "Turkish saddle". It is a constructed (radiological) point in the midsagittal plane.
Se	Sella entrance	The midpoint of the entrance to sella.
So	Sphenooccipital synchondrosis	The junction between the occipital bone and the basisphenoidal bones.
Si	Floor of Sella	The lowest point on the contour of the sella turcica (Sassouni).
Sp	Dorsum Sella	The most posterior point on the sella turcica outline (Sassouni).
Te	Temporale	The intersection of the cribriform plate and the anterior wall of the infra temporal fossa; superior point on the roof of the orbit.

Lateral Skeletal Landmarks Cont'd		
Xi	Xi point	Represents the centre of the ramus, approximately equal to the location of the lingula (Ricketts). It is located by constructing a rectangle of four planes; two perpendicular planes from Frankfort horizontal through points R1 and R2, and two horizontal planes parallel to Frankfort horizontal thorugh points R3 and R4. Xi is the centre of this rectangle. [R1 - The deepest point on the curve of the anterior border of the ramus, one half the distance between the inferior and superior curves. R2 - A point located on the posterior border of the ramus opposite R1. R3 - A point located at the centre and most inferior aspect of the sigmoid notch of the ramus. R4 - A point on the lower border of the mandible directly inferior to the centre of the sigmoid notch, (R3).
Frontal Landmarks		
Ag	Antegonion	The highest point in the antegonial notch.
Cd	Condylar	The most superior point of the condylar head.
Cor	Coronoid	The most superior point of the coronoid process.
Iif	Incision inferior frontale	The midpoint between the mandibular cental incisors at the level of the incisor edges.
Isf	Incision superior frontale	The midpoint between the maxillary cental incisors at the level of the incisor edges.
Lo	Latero-orbitale	The intersection point between the external orbital contour laterally and the oblique orbital line.
Lpa	Lateral piriform aperture	The most lateral aspect of the piriform aperture.
Lm	Mandibular molar	The most prominant lateral point on the buccal sur face of the second deciduous or first permanant mandibular molar.
Lzmf	Zygomaticofrontal lateral suture in-point	Point at the lateral margin of the zygomaticofrontal suture.
Ma	Mastoid	The lowest point of the mastoid process.
M	Mandibular midpoint	Located by projecting the mental spine on the lowermandibular border, perpendicular to Ag-Ag.

Frontal Landmarks Cont'd		
Mal	Malare	Midpoint of the intersection between the projection of the coronoid process and lower contour of the malar bone.
Mf	Mental foramen	The centre of the mental foramen.
Mo	· Medio-orbitale	The point on the medial orbital margin that is closest to the median plane.
Mx	Maxillare	Maximum concavity on the contour of the maxilla between malare (Ma) and the maxillary first molar.
Mzmf	Zygomaticofrontal medial suture in-point	Point at the medial margin of the zygomaticofrontal suture.
NC	Neck of Crista Galli	Most constricted point of the projection of the perpendicular lamina of the ethmoid.
OM	Orbital midpoint	The projection of Lo-Lo of the top of the nasal septum at the base of the crista galli.
Tns	Top nasal septum	The highest point on the superior of the nasal septum.
Um	Maxillary molar	The most prominant lateral point on the buccal surf-face of the second deciduous or first permanant maxillary molar.
Za	Point zygomatic arch	Point at the mostlateral border of the centre of the zygomatic arch.
Dental		
APOcc	Anterior point for the occlusal plane	Constructed as the midpoint of the incisor overbite in occlusion.
Ap$\underline{1}$, Isa	Apicale 1, Incisior superius apicalis	The root apex of the most anterior maxillary incisor.
L1	Mandibular central incisor	The most labial point on the crown of the mandibular central incisor.
Iii	Incisor inferius incisalis	The tip of the crown of the most anterior mandibular incisor.
Ap$\bar{1}$, Iia	Apicale 1, incisior inferius incisalis	The root apex of the most anterior mandibular incisor.
Isi	Incisor superius incisalis	The tip of the crown of the most anterior maxillary incisor.

Dental Cont'd		
L6	Mandibular first molar	The tip of the mesiobuccal cusp of the mandibular first permanent molar
LM	Lower molar	A point on the occlusal plane perpendicular to the distal surface of the crown of the lower first molar
PPOcc	Posterior point for the occlusal plane	The most distal point of contact between the most posterior molars in occlusion
UM	Upper molar	A point on the occlusal plane perpendicular to the distal surface of the crown of the upper first molar
U1	Maxillary central incisor	The most labial point on the crown of the maxillary central incisor.
U6	Maxillary first molar	The tip of the mesiobuccal cusp of the maxillary first permanent molar
Soft Tissue		
C	Cervical point	The innermost point located between the submental area and the meck located at the intersection of the lines drawn tangent to the neck and submental areas.
Cm	Columella	The most anterior and inferior point of the soft tissue nose profile.
G	Glabella	The most anterior soft tissue point of the frontal bone.
Ils, sm	Inferior labial sulcus, submentale	A point at the innermost curvature of the lower lip. Alternately, the junction of the labiomental fold.
Ls	Labrale superius	The maximum convexity of the upper lip.
Li	Labrale inferius	The maximum convexity of the lower lip.
Me', Ms	Soft tissue Menton	The point on the lower contour of the chin opposite to the hard tissue menton.
N', n, Ns	Skin Nasion	Located at the point of maximum convexity between the nose and forehead.
Pog', Pos	Soft tissue Pogonion	The most anterior soft tissue point of the chin.
Pr, no, Pn	Pronasale	The tip of the nose.
Si	Mentolabial sulcus	The point of greatest convexity in the midline between the lower lip (li) and chin (Pog').
Sn, sn	Subnasale	The point at which the nasal septum merges mesially with the upper cutaneous lip in the midsagittal plane.

Soft Tissue Cont'd		
St', sto	Stomion	A point at the interlabial junction of the mouth where the upper and lower lips connect; the central point of the interlabial gap.
Stm_s, Sts	Stomion superius	The uppermost point on the vermillion border of the upper lip.
Stmi, Sti	Stomion inferius	The lowermost point on the vermillion border of the lower lip.
Th	Throat point;	The point at the junciton of the neck and the submandibular soft tissue.
Tr, tr	Trichion	The superior juncture of the soft tissue outline with the hairline.

Table 2. Definition of common cephalometric planes and lines

Sagittal Skeletal Planes		
APog	A Point-Pogonion	A sagittal reference relating the inclination and anterior posterior position of the upper and lower incisors to the jaws irrespective of the cranial base (Ricketts).
ArGo	Articulare-Gonion	**Ramal Plane:** Represents measurement of the length of the ramus (Saussoni).
BaN	Basion-Nasion	Represents the cranial base (Ricketts).
BoN	Bolton point-Nasion	**Bolton Plane**: Represents the cranial base.
CdGo	Condylion-Gonion	**Ascending Ramus:** Represents the length of the ramus.
FH	Porion-Orbitale	**Frankfort Horizontal:** Represents the cranial base (Downs). Orbitale may be averaged or a point 4.5mm above the geometric centre of the ear rod (Tweed).
GoGn	Gonion-Gnathion	**Mandibular Plane:** Represents the mandibular position (Steiner). Also considered to be plane tangent to the lower border of mandible (Tweed).
MeGo	Menton-Gonion	Reprersents the extent of the mandibular base (Saussoni).
NPog	Nasion-Pogonion	**Facial Plane:** A sagittal reference plane.

Sagittal Skeletal Landmarks Cont'd		
NA	Nasion-A	A sagittal reference line for the maxilla's anterior-posterior position (Steiner).
NB	Nasion-B	A sagittal reference line representing the anterior-posterior position of the mandible (Steiner).
Occ Pl (fun)		**Functional occlusal plane:** A line bisecting the molar and premolar occlusion of the cusp tips (Ricketts).
Or-Ant clinoid tangent		**The infra orbital plane:** A line drawn tangent to the most inferior point on the floor of the orbit (Or) and the anterior clinoid (Sassouni).
Optic Pl		**The Optic plane:** constructed by drawing a bisecting line through the angle formed by the supra and infraorbital planes (Sasouni).
OP or Occ	APOcc-PPOcc	**Occlusal Plane:** A line bisecting the first molar occlusion and incisor overbite (Downs/Steiner).
PP or Pal	ANS-PNS	**Palatal Plane:** Represents the palatal plane or angle of the maxilla.
PtGn	Pterygo maxillar -Gnathion (constructed)	**Facial Axis:** Very similar to Downs' Y-axis (Ricketts).
PTV	Pterygoid Vertical	**Pterygoid Vertical:** Used to represent the posterior border of the maxilla. A line perpendicular to FH and tangent to the posterior contour of the PTM at the level of the foramen ovale.
SN	Sella-Nasion	Anteroposterior extent of the anterior cranial base. Represent the cranial base in the midsagittal plane (Steiner).
Te-Ant Clinoid tangent		**The supraorbital plane:** A line drawn tangent to the most superior point on the roof of the orbit (Te) and the anterior clinoid. also: **parallel to supraorbital:** a line drawn tangent to the lowest point of the contour of sella turcica (Si) and parallel to the supraorbital plane (Sassouni).

Frontal Skeletal Lines		
AgAg	Inter-Antegonial	**Mandibular width:** (Ricketts)
AgMe	Antegonial-Menton	**Mandibular body length:** (Grummons)
CoAg	Condyle-Antegonial	**Mandibular ramus height:** (Grummons)
Co-MSR Perp	Condyle-MSR perpendicular	**An estimate of ramal flare** (Grummons)
MSR	Cg-ANS	**Mid-sagittal reference plane**: Constructed (Grummons)
NC-NC	Nasal cavity-Nasal cavity	**Nasal cavity width:** Used in combination withpalatal plane (Ricketts)
Z-Z	Inter-Zygomatico -frontal sutures	Z plane: Estimate of interorbital width (Grummons)
Soft Tissue Planes		
"E" Line	no-pog	Soft tissue "Aesthetic line": In the primary dentition the upper lip (ls) should be behind the line and the lower lip (li) 1mm anterior. In the adult dentition, ls should be 1mm behind the line and li on the line (Ricketts).
"S" Line		Constructed from the soft tissue contour of the chin (Pog') to the middle of an "s" formed by the lower border of the outline of the soft tissue nose. Ideally ls and li should lie on this line (Steiner).
Holdaway line	pog-ls/li	Constructed by drawing a tangent to Pog' and the most protrusive lip surface, either ls or li, and extending it to FH. Upper lip should be tangent to line and lower lip either tangent or slightly behind.
"Z" or profile Line	pog-ls/li	Constructed the same as the Holdaway line. Additionally, "Z" line should form an angle of 80 deg with FH (Merrifield).
HP		**Horizontal reference plane**: constructed by drawing a line through Nasion 7 degree up from the SN line (Legan-Burstone).

Reference lines

In any cephalometric analysis, it is necessary to establish a reference area or reference line from which to compare serial measurements. Three horizontal reference lines representative of the cranial base have been proposed.

The Frankfort Horizontal (FH), a plane between Porion and Orbitale (Po-Or) has been adopted as the best representation of the natural orientation of the skull, however, the biological significance of this plane and difficulty in locating it have often been contentious issues. The construction of this plane is dependent on the location of anterior and posterior landmarks which can be difficult to locate reliably on a cephalometric film. The points are also not midsaggital, there being left and a right representations, while any line joined between these two points is merely an "averaged" line between two constructed points. Additionally, FH may not be parallel to the ground and may not correlate with the subject's head posture.

Sella-Nasion (S-N) is easily and reliably detected on cephalometric radiographs and is constructed from mid-sagittal landmarks. Unfortunately the position of sella is highly variable and is almost completely unrelated to facial structure. A "true horizontal" line, established by NHP, which coincides with the line of vision parallel to the floor has also been proposed as a horizontal reference plane.

There is no standard vertical reference line. The vertical relationship is usually expressed as an angular variation from the horizontal line or a ratio proportion from the anterior to the posterior face.

CLINICAL USE

The skull can be considered to be composed of five major structural components including the cranium and the cranial base, the skeletal maxilla and mandible and, the maxillary and mandibular dentition. All cephalometric analyses describe the interrelationship of these parts or may describe the form of the individual unit. These relationships may be described in both the vertical and horizontal plane.

Methods of description

There are four ways to describe the relationship of these structural units:

Linear measurement

Measures the distance between two landmarks, which can be compared directly to comparative norms or analyzed as proportions. The disadvantage of this method is that the size of the individual is not taken into account. Age and size weighting is therefore important with all linear measurements. An example of an extreme form of linear analysis is the Coben analysis (1955).

Angular measurement

Measures the angles formed between constructed planes. As angles are a ratio scale measurement, they inherently incorporate the effect of size when comparisons are made. Analyses such as the Downs (1948) and Steiner (1953, 1959) are predominantly angular, while Ricketts (1957, 1960a,b), COGS (Burstone *et al.*, 1979) and McNamara (1984) comprise both linear and angular considerations.

Archial or geometric analyses

Determine structural relationships by comparing the form of a series of arcs or geometric connections between landmarks. There are no numeric standards or comparisons to normal groups, rather the visual impact of the relationships and conformity to geometric principles become the guiding principles. While most training for orthodontists is centered on linear and angular comparisons, experience and the development of intuitive understanding of proportions make this type

of analysis the most uniformly used in clinical practice. The Sassouni analysis (1955, 1969) is the prototypical archial analysis.

Graphic or template analyses

Express normative data graphically and compare dentofacial form directly with an ideal normal via a template. This technique assists the clinician in the recognition of relationship patterns. The California analysis (Wylie, 1952) provides an example of this approach.

Although impressive in their visual impact, both the geometric and template analyses do not lend themselves to statistical analysis of treatment results. Template analysis is very useful in overviewing the general picture of the skeletal relationship and should be used as a adjunct to appreciate the diagnosis the numbers may indicate. As computer analysis becomes more prevalent, the template analysis will gain in importance in cephalometric diagnosis.

Procedure

Film quality assessment

An analysis can only be performed on a cephalometric film if it satisfies two criteria: Adequate film quality and acceptable patient positioning. Compromise in either of these areas will severely reduce observer reliability, jeopardise location of cephalometric landmarks and result in inaccurate cephalometric measurement and analysis.

Film assessment begins with an appreciation of cephalometric film radiodensity, contrast and detail. Density refers to the overall blackness or darkness of the radiograph. This is assessed by comparing those structures with the greatest density or are most radiolucent, such as the frontal and maxillary sinuses, with those that produce images with the least density or are radiopaque, such as the temporal bone or lower border of the mandible. Radiolucent structures should be clearly distinct from adjacent opaque areas and appear substantially darker. If the entire film is light or hazy, there is inadequate density for cephalometric interpretation and another exposure should be made, ensuring correct milliamperage, kilovoltage and exposure time.

Contrast is used to describe the number of shades of gray visible within a radiographic image: High contrast refers to few shades of gray and mainly black and white areas while low contrast refers to the presence of many shades of grey. Cephalometric contrast depends upon the equipment used to produce the image as well as size and structure of the patient. High kilovoltage exposure techniques, as are often used in cephalometrics utilizing panoramic machines or medical systems, are preferable as they reduce patient exposure but also produce dense images with optimal contrast. Contrast can be assessed by comparing the visual distinction between structures with subtle differences in either depth or type of hard tissue. Adequate contrast exists if differences can be determined between enamel and dentin or the trabecular pattern of the mandibular symphseal region can be observed.

Detail refers to the sharpness of the radiographic image. This can be determined by carefully examining the lower border of the mandible for sharp, clear lines. Most causes of unsharpness are related to inherent penumbra, however, motion artifact, particularly when exposure times of greater than 0.5 seconds are used, can contribute significantly to loss of detail.

Image assessment

The second element of cephalometric appraisal involves assessment of the image for correct patient position and identification of abnormal structures.

The cervical spine should show equal joint space from the cranial base to the vertical process of C1 and from the processes of C1 to C2. The neck should be examined for normal posture and curvature. The pituitary fossa should be examined for normal size and shape. The sinuses should be examined for normal size and development and clarity including the frontal (especially present in mature males), ethmoidal, sphenoidal, maxillary, nasal and mastoid air cells.

The airway should be patent from the nares to trachea and any enlargement or changes in the adenoid or tonsilar tissues as well as position of the tongue noted. The length of the soft palate and its position should be observed. At this preliminary stage, soft tissue relationships such as the nasolabial angle, lip competency, depth of mentolabial fold and throat length can be noted.

The posterior teeth should always be contacting in maximum intercuspation unless the radiograph has been taken to visualize the condyle. Similarly FH should be approximately parallel to the inferior border of the film. Any deviation, particularly with obvious curvature of the cervical spine, suggests incorrect positioning and the film should be retaken.

Specific cephalometric analyses

Analyses vary considerably and range from simple, single purpose applications to elaborate and often confusing monographs. Analyses may include one or all of the following components and possess clinical, research or surgical applications: dental, skeletal (in either the sagittal, vertical, transverse or basilar orientation), soft tissue, proportional or template analysis. The following classic analyses will be specifically considered: Downs, Steiner, Tweed, Sassouni, (Figure 3) Ricketts, Bjork, Harvold and McNamara (Figure 4). Specific definitions and normative values of common cephalometric lengths and angles cited in the analyses are shown in Table 3.

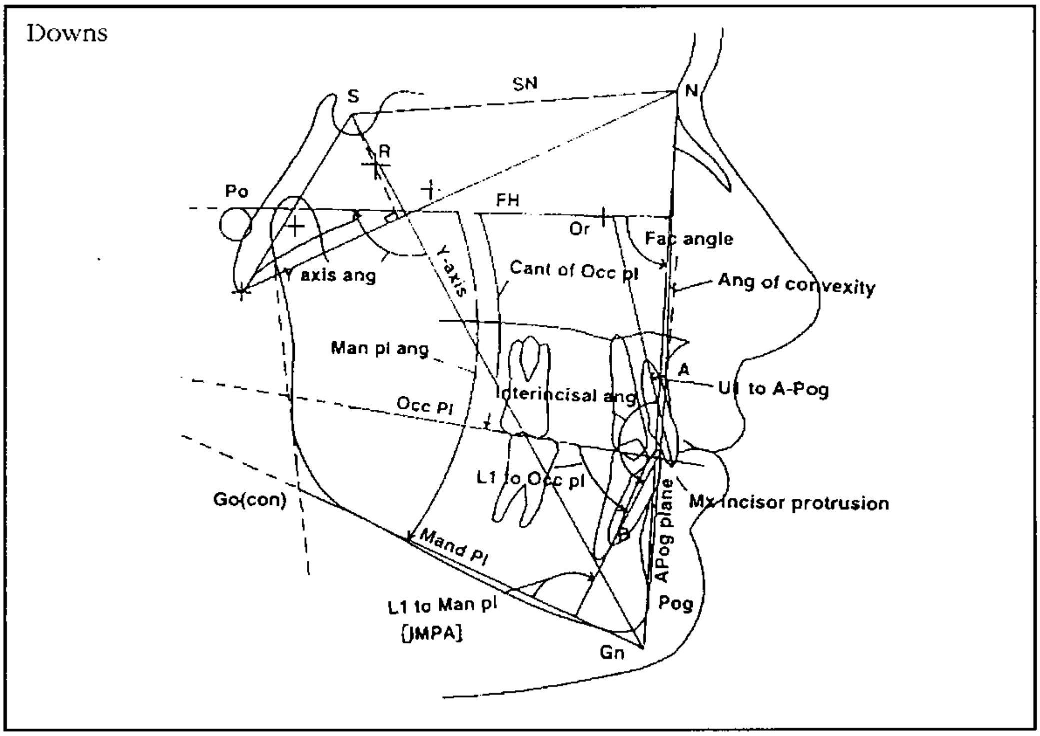
THE DOWNS ANALYSIS

The Downs analysis (1948, 1952) was the first to comprehensively describe the nature of the facial skeletal pattern of a normal occlusion as well as appraise the relationship of the dentition and alveolar process to the facial skeleton. His analysis is based on a sample of 20 American Caucasian children aged 12 to 17 years with "excellent" occlusions, with approximately equal sex distribution.

He divided his analysis into parts that measured skeletal positions, and those that measured tooth positions, with five sections in each division.

The cranial base is the "Bolton Triangle", a line connecting N-S-Bo-N. As no measurements to Frankfort Horizontal are made, this plane is the cranial base for measurement purposes. Superimpositions are based on "registration point" (R), a landmark located by taking the midpoint of a perpendicular from the Bolton plane to the centre of Sella turcica. When serial tracings are studied, they may be registered on this point with their Bolton planes parallel.

The maxilla's position is not related to the cranial base in this analysis however is interpreted from the vertical reference of the mandible to the cranial base principally by the angle of convexity. The facial angle demonstrates the position of the mandible to the cranial base, while the mandibulo-maxilla relationship is measured by the AB plane. The interincisal angle together with U1 to APog describe the relationship of the maxillary dentition to the mandible and mandibular dentition respectively. Similarly, the relationship between the mandibular dentition to the mandible and averaged dentition is defined by IMPA and L1 to occlusal plane. The Downs definition of the mandibular plane is unusual in that it is constructed tangent to the anterior and posterior lower border of the mandible.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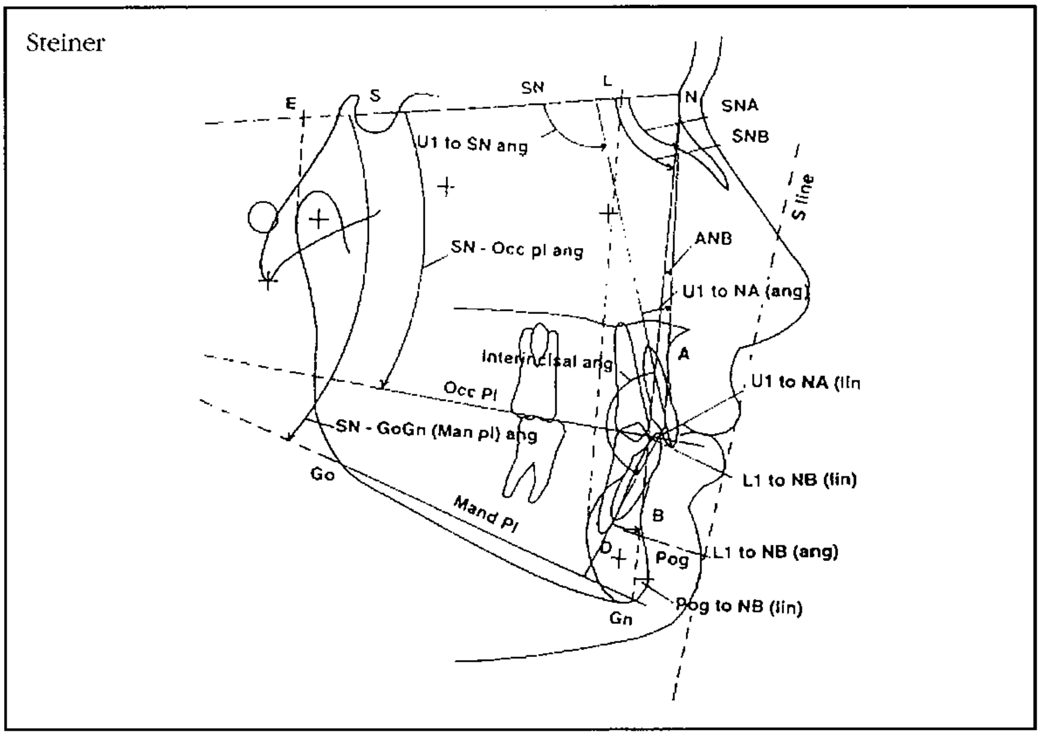
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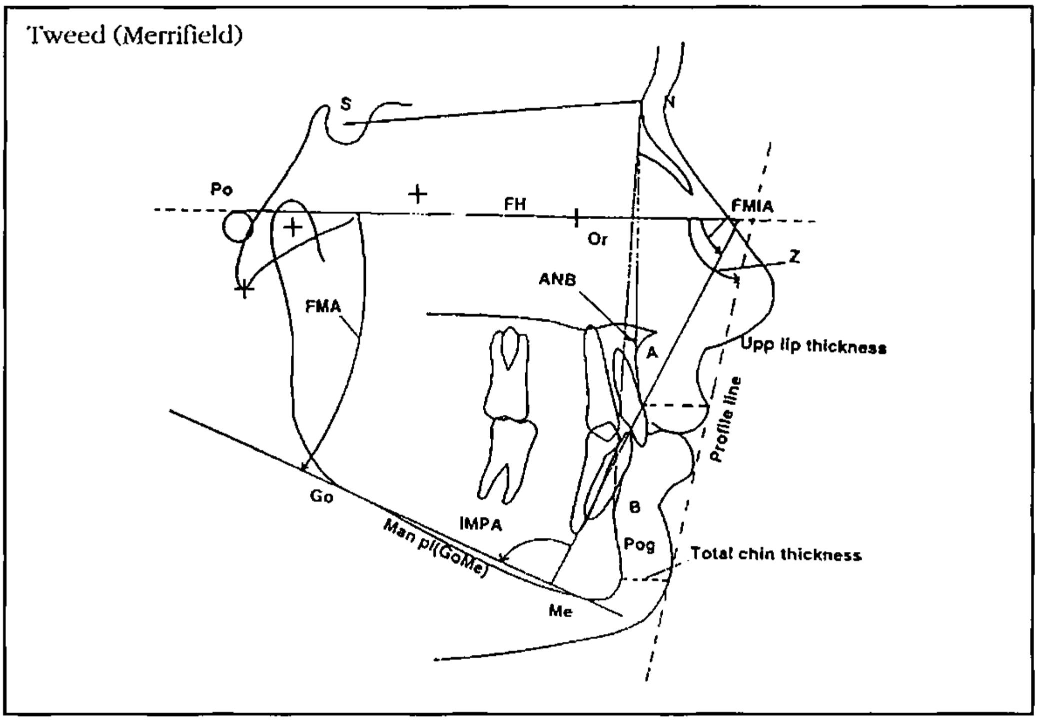


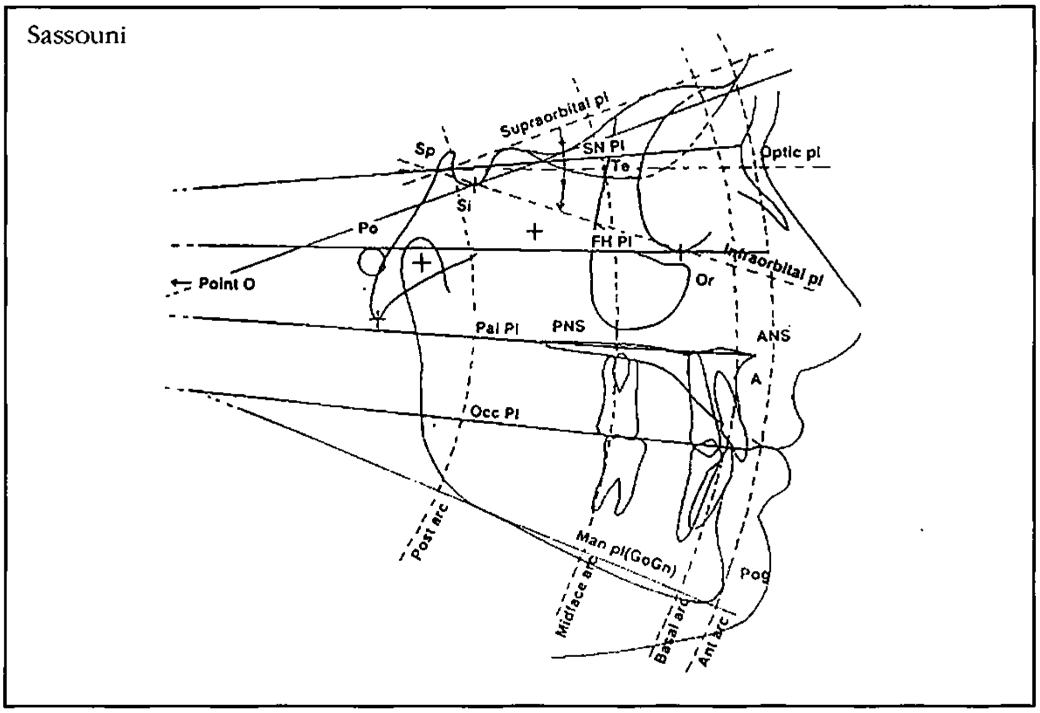
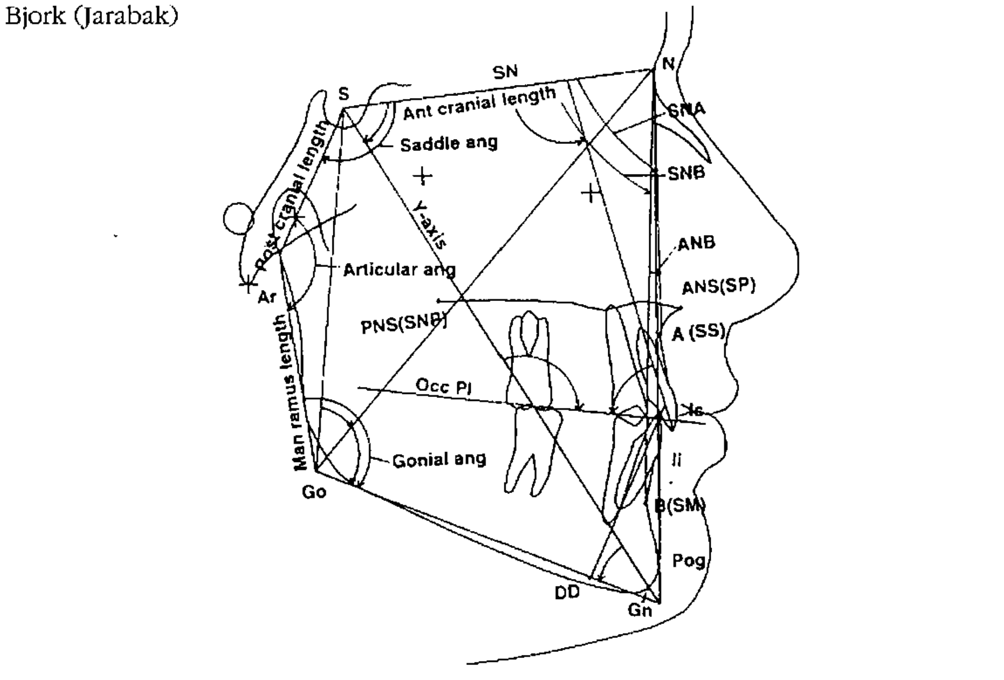
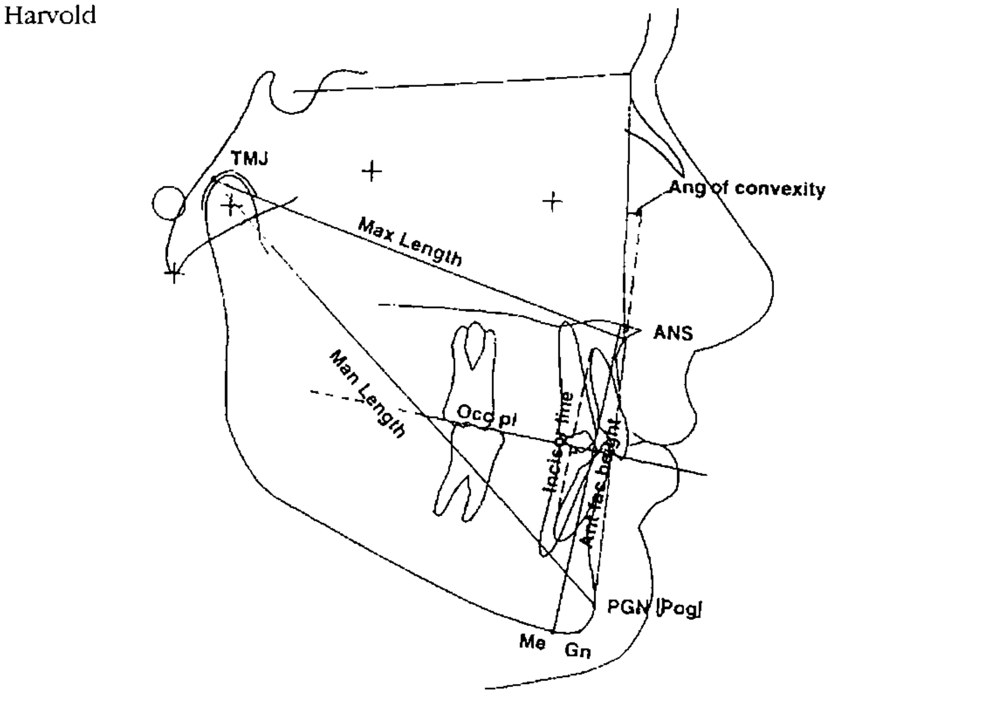


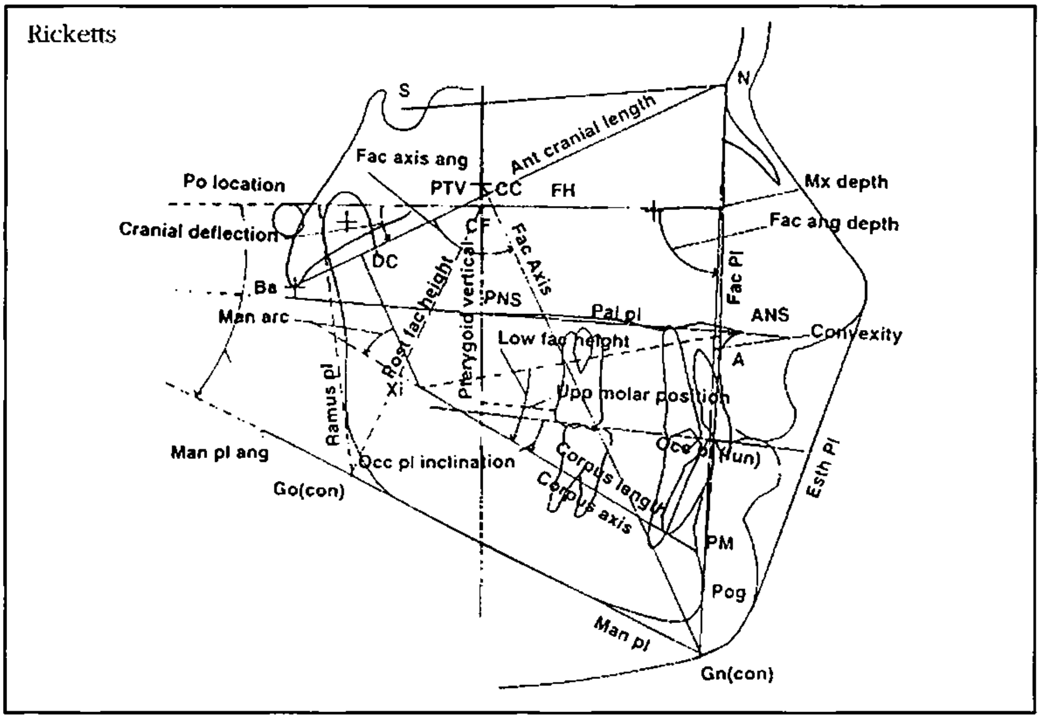
Fig. 3. Common cephalometric analyses: Downs, Steiner, Tweeds and Sassouni.

Bjork (Jarabak)



Harvold





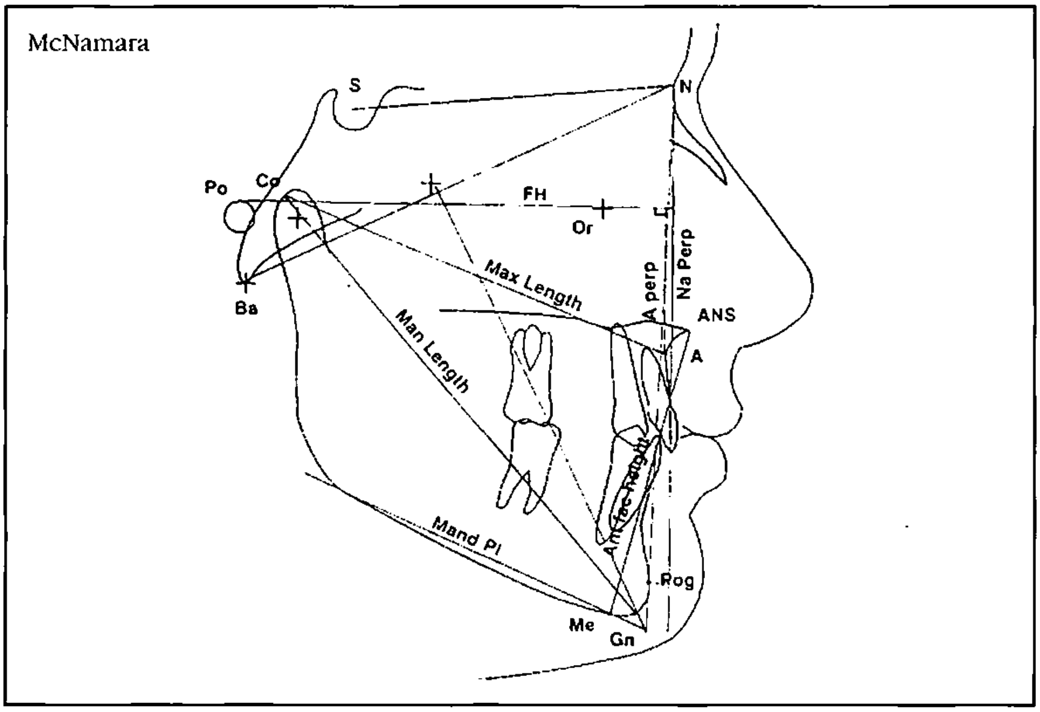


Fig. 4. Common cephalometric analyses: Bjork, Harvold, Ricketts and McNamara.

Table 3. Definition and normative values of common cephalometric lengths and angles.

Cranial Base		
SN to FH	5±6°	Comparison of principal cranial base reference planes.
BaN to FH	27± 3°	**Cranial deflection**: Indicates basal and skeletal dysplasia.
SN	M: 83±4mm F: 77±4mm	**Anterior cranial length**: Describes the length of the anterior cranial base.
SBa	M: 50±4mm F: 46±4mm	**Posterior cranial length**: Describes the length of the posterior cranial base.
BaN	M: 120±5mm F:112±5mm	**Saddle length**: Describes the total cranial base length.
NS to SAr	123±5°*	**Saddle angle**: Describes the flexure or bend between the anterior and posterior cranial base.
NS to SBa	130± 4.5°	Used to describe the cranial base. Alternate to saddle angle.
Ba to PNS	52±4mm	Used to determine the horizontal position of the hard and soft palate particularly in airway obstruction.
MAXILLA **Maxilla to other structures**		
A to Facial plane	2±2mm @ 8.5 years	**Convexity**: Decreases 0.2mm per year - Measures the relationship of the maxilla to the mandible. Is measured by the linear perpendicular distance between point A and the facial plane.
SNA (SN to NA)	82 ± 3°	Describes the horizontal position of the maxilla to the cranium. (Steiner)
CoA	85.0	**Midfacial length:** Describes length of midfacial region.
FH to NA.	90±3°	**Maxillary depth:** Indicates horizontal location of the maxilla relative to the cranial base. Also known as Lande's angle.
NA to APog	0±5.1°	**Angle of Convexity:** A measure of the protrusion of the maxillary part of the face to the total profile (Downs).
Pal plane to NB	85±3°	Indicates orientation of maxilla to mandibular protrusion.

Maxilla to other structures Cont'd		
Pal plane to BPog	86±3°	Relates maxilla orientation to mandibular protrubrence.
Pal plane to FH	1±3.5°	Relates vertical position of the maxilla to the cranial base.
SN to ANS	87±4°	Alternate to BNA: Describes horizontal position of maxilla to cranium.
Intermaxillary		
DiU6 to PTV	Age + 3mm	Measures horizontal dimension of posterior component of maxilla.
PNS-ANS	M: 62±4mm F: 57±4mm	**Palatal plane length:** Indicates contribution of maxilla to horizontal dimension.
PTM-ANS	M: 65±3mm F: 61±4mm	Alternate anteroposterior maxillary length measurement.
MANDIBULAR **Mandible to other strutures**		
BaN to NB	80±3.7°	Describes the horizontal position of the mandible to the cranium.
CoXi to FH	76±3°	**Ramus position**: Relates the mandible to the cranial base.
Mand plane to FH	26±4.5°	Describes the growth pattern of the mandible.
NPog to FH	M: 83±4°* F: 86±3°*	**Facial angle**: an expression of the degree of recession or protrusion of the chin relative to FH cranial base (Downs).
NPog to FH	86.5±3.1mm	**Facial depth**: the horizontal relation of the mandible to the cranium.
NB to FH	82±3°	Relates maxilla to cranial reference plane.
NPog to M and plane	68±3°	Relates facial profile to mandibular plane.
Pog to NB	2±2mm	Determines the relationship between the prominence of the chin and that of the lower incisor (Steiner).

Mandible to other strutures Cont'd		
Po to Ptm	-39±2.2mm	**Porion location**: Relates the mandibular condyle to the cranial base.
SNB	80±3°	Indicates position of mandible to cranial base (SN) (Steiner).
Intermandibular		
Ptm-Go	54.8±3.3mm	**Ramus height:** Describes the shape of the mandible, where low values indicate a more vertical pattern.
CoPtm to Cf-Xi	76±3°	**Ramus Xi position**: Describes the horizontal position of the Ramus, where high values may indicate abnormal mandibular growth.
CoXi to XiPm	26±4°	**Mandibular arc**: Describes the shape of the mandible.
GoGn	M: 86±4mm F: 81±4mm	**Mandibular body length:** Determined along mandibular plane.
XiPog	65±2.7mm	**Mandibular length:** Indicates the form of the mandible anteroposteriorly.
CoGo	M: 66±4mm F: 60±3mm	**Ramal length:** Alternate to PtmGo; uses internal points on ramus.
CoPog	M: 131± 6mm F: 121±4mm	**Total mandibular length**:
CoGn	128.2±4.2mm	Alternate to CoPog, describing total mandibular length.
CoB	M: 117±5mm F: 102±5mm	Indicates maxillary dental base extension.
Interarch		
AOBO	M: -1mm F: 0mm	**Wits**: Constructed relationship indicative of maxilla position relative to the mandible (Merrifield/Wits).
Pal plane to Mand plane	82±4°	Anterior divergence of maxilla/mandible.
AB to Facial plane	-4.6±3.7°	Measures the relation of the anterior limit of the denture bases to each other and to the profile (Downs).
AN to NB (ANB)	M: 3±2° F: 2±2°	Magnitude of the horizontal skeletal jaw discrepancy between the maxilla and mandible (Steiner).

DENTOSKELETAL **Maxillary teeth - Skeletal**		
U1 to APog	M: 2.7±3.1mm F: 3.5±2.3mm*	A measure of the horizontal relation of the maxillary dentition to the mandibulo/maxillary profile.
U1 to APog	28±4°	**Maxillar incisor inclination:** Describes amount of maxillary incisor tipping related to the mandibulo-maxillary profile.
A to facial plane (NPog)	2±2mm	**Convexity**: Describes the horizontal relation of the maxilla to the mandible.
U1 to NA (angular)	22±6°	Indicates protrusive or retrusive position of maxillary dentition relative to the dental basal bone (Steiner).
U1 to NA (linear)	4±3mm	Indicates horizontal bodily displacement of maxillary dentition relative to the dental basal bone (Steiner).
U1 to SN	104±5°	Descriptor of maxillary incisor to cranial base (SN) (Steiner).
MeU6 to LaU1	M: 27±2mm F: 25±2mm	**Maxillary dental arch length**: Indicates contribution of dentition to overall horizontal maxillary length.
Mandibular teeth - Skeletal		
L1 to APg	M: 3±3mm F: 1±3mm	A measure of the horizontal relation of the mandibular dentition to the mandiblo/maxillary profile*.
L1 to APg	M: 22±4° F: 24±5°	**Mandibular incisor inclination**: Describes amount of mandibular incisor tipping related to the mandiblo/maxillary profile*.
L1 to mand plane	91.4±3.8° (Downs) 90° (Tweed) 95±7° (Ricketts)	**IMPA**: The axial inclination of the mandibular incisor teeth to the mandibular plane (GoMe) indicates the relative protrusion/retrusion of the mandibular dentition (Downs). Mandibular Plane in Tweeds analysis is constructed differently to Downs.
L1 to FH	65±5°	**FMIA:** Indicative of inclination of lower incisor teeth with respect to FH (Tweed).
L1 to NB (angular)	25±4°	Indicates protrusive or retrusive position of mandibular dentition relative to the dental basal bone (Steiner).

Mandibular teeth - Skeletal Cont'd		
L1 to NB (linear)	4mm	Indicates horizontal bodily displacement of mandibular dentition relative to the dental basal bone (Steiner).
L1 to Occ plane	14.5±3.5°	The sign of the angle less 90deg (+/-) indicates retroinclination or protrusion of the mandibular anterior teeth relative to the occlusal plane (Downs)
L1 to occ plane fun	1.25±2mm	**Mandibular incisor extrusion**: Used to identify degree of overbite attributable to mandibular dentition.
Mandibular - Maxillary teeth		
U1 to L1	M: 135.4±5.8° F: 130±6°	**Interincisal angle:** Lines drawn through the long axis of the upper and lower incisors teeth indicate the procumbancy of the incisors teeth (Downs, Steiner)*.
CoA minus CoGn	29.3±3.3mm	**Maxillo-mandibular Differential**: Used to evaluate a horizontal skeletal imbalance.
DiL6 to DiU6	-3±3mm	**Molar relation:** Describes horizontal relationship of molar occlusion according to Angle's classification. Measured along functional occlusal plane.
Mx canine tip to Mn canine tip	-2±3mm	**Canine relation:** Also measures horizontal relationship according to Angle's classification at the canines. Measured along functional occlusal plane.
Is to L1	2.5±2.5mm	**Incisor overjet**: describes the horizontal occlusion of the anteriors. Measured along functional occlusal plane.
Is to L1	2.5±2.5mm	**Incisor overbite**: describes the vertical occlusion of the anteriors. Measured paralell to functional occlusal plane.
SKELETAL **Vertical**		
FH to Occ plane	9.3±3.8°	**Cant of the Occlusal plane**: Vertical relationship of the dentition to the cranial base (FH) and can be indicative of facial type tendancy (Downs).
SGn to FH	59.4±3.8°	**Y Axis**: Vertical relationship of the anterior mandible to the FH and is an expression of the direction of mandibular growth (Downs).
SGn to SN	66±7°	**Y Axis**: Identical to above using different cranial base (SN) (Steiner).

Vertical Cont'd		
FH to Man plane	21.9±3.2°	**Mandibular plane angle:** Vertical measure of the relationship between the cranial base (FH) and mandible (Downs).
SN to Occ plane	14°	Entire dentition relationship to cranial base (SN) (Steiner).
SN to GoGn	32±5°	Relates mandible to cranial base (SN) and is indicative of vertical pattern (Steiner).
FH to GoMe	25° (ave.) M: 28° F: 25°	**FMA:** Vertical measurement, indicative of growth direction (Tweed).
Occ Plane to Xi	0±3mm	Linear relationship of the dentition to the mandible.
Occ plane to Corpus axis	22.5±4°	Describes the inclination of the dentition to the mandible.
ANSXi to Xi Pm	47±4°	**Lower face height:** Indicative of the vertical relationship of the lower face as a component of mandibular excess or deficiency and indicates divergence of the maxilla to the mandible.
CFGo	55±3.3mm	**Posterior face height**: Vertical dimension of the ramus with relation to the cranium.
NMe		**Anterior facial height**: Vertical dimension of the symphysis with relation to the cranium.
CFGo/NMe	0.6-0.62	**Anterior/posterior ratio**:
MeANS	72±3mm	**Lower anterior face height:**
CCGn to BaN	90±3.5°	**Facial axis:** Describes horizontal and more accurately vertical growth development. Similar to Y-axis (Downs) but measured in relation to NB cranial reference.
NCF to CFA	53±3°	**Maxillary height**: Relates vertical position of the maxilla to the cranial base.
Horizontal		
FH to NA	90±3°	**Maxillary depth**: Determines the horizontal relation of the maxilla with relation to the cranium.

SOFT TISSUE		
Z line to FH	M: 77° F: 78°	**Z Angle**: Good indicator of soft tissue profile, responsive to maxillary incisor position (Merrifield).
Low lip to E line	-1±2mm	Describes lip protrusion*
ANS to Upp lip	24±2mm	**Upper lip length**: indicative of upper lip strain.
Sto to occ plane (fun)	-3±2mm	**Lip embrasure - occlusal plane**: Used to appraise soft tissue and nature of smile.
sn tangent to upp lip vermillion	115±5°	**Nasolabial angle**: Used to appraise soft tissue profile of the nose.
All values are from Bell, Proffit and White norms (Bell WH, Proffit WR, White RP (1980) *Surgical Correction of Dentofacial Deformaties, Volume 1*. WB Saunders, Philadelphia, PA.) unless annotated by asterix (*).		

The dentition to the cranial base is measured by the cant of the occlusal plane, the vertical position of the mandible to the cranial base is measured by the mandibular plane angle and the vertical relationship of the anterior mandible to the cranial base is determined by the Y axis, the first defined index of growth tendancy.

The Downs analysis is a visual representation of sagittal variation. Soft tissues were not considered and although standard norms of different races, age groups and gender were studied later, the original sample size was extremely small and possessed great variations from other samples. Vorhies and Adams (1951) provided a supplementary graphic chart to this analysis incorporating ten measurements of the analysis. A line of small arrows down the centre of the diagram identifies the mean figure for each measurement, and the extent of the polygon outlines the range of each measurement. A dotted line represented the plot of the measurements of the patient. The top half of the diagram charts those measurements related to skeletal configuration, whereas the lower half shows denture relationships. The chart is called the "Wigglegram", as treatment should position the patient "wiggle" inside the normal "wiggles".

THE STEINER ANALYSIS

The Steiner analysis (1953, 1959) was the first to propose that individual measurements from skeletal, dental and soft tissue components be interrelated and to describe a "VTO" (visualized treatment objective) for treatment planning based on cephalometric data, arch length discrepancy and selected treatment objective.

It is a sagittal analysis, providing excellent visualization of incisor position by determination of both angular and linear measurements relative to NA and NB. Measurements were initially represented graphically as "Steiner sticks," and based on norms either

derived from one Hollywood starlet or more plausibly Riedel's sample (Riedel, 1952), representative of adults or late adolescent patients.

The cranial base is exclusively SN, which is also used for serial registration with the registration point on Sella. Maxillary position is measured by the angle SNA. However comparison of measurements to norms for this angle are only valid if the SN plane is normally inclined to the true horizontal and the position of N is normal. Mandibular position is defined with respect to the cranial base by the angle SNB while the angle ANB measures the magnitude of the skeletal jaw discrepancy between the mandible to the maxilla. ANB angle is however influenced by factors other than the anterior-posterior difference in jaw position including vertical face height and the anterior-posterior position of nasion

The maxillary dentition is not related to the cranial base but to the maxilla only by three parameters, U1 to NA (linear and angular) and U1 to SN, whereas the mandibular dentition is described relative to the mandible by L1 to NB (linear and angular) and Pog to NB distance and defined with respect to the maxillary dentition by the interincisal angle. The angle SN to Occlusal plane is used to relate the dentition to the cranial base. The vertical position of the mandible to the cranial base is indicated by SN to GoGn. The Y axis, measured from SN, is also defined.

A major advantage of this analysis is that it has acceptable compromises for ANB and incisor position and angle. Unfortunately relating the jaws to cranial reference points can give rise to a number of inconsistencies as the position of Sella has a great bearing on the SNA and SNB measurements. Longer anterior cranial length, long facial height and rotation of the occlusal and palatal plane may also mask ANB discrepancies.

THE TWEED ANALYSIS

This analysis (Tweed, 1954, 1966, 1969) is not a total facial analysis, but is based on the deflection of the mandible, as measured by the Frankfort-mandibular plane angle (FMA), and the posture of the lower incisor. The objectives of the analysis are to determine the position that the lower incisor should occupy at the end of treatment and establish a prognosis of the treatment result, based on the configuration of the "Tweed Triangle". The normative sample consisted of 100 cases with satisfactory facial esthetics, and a further 3500 (Broadbent, 1975) which reasonably represent Caucasians of Northern European decent.

The Tweed Triangle is formed by a derived FH plane, the mandibular plane, and the long axis of the lower incisor. The three angles thus formed are the Frankfort-mandibular plane (FMA), describing the vertical relationship, the lower incisor to mandibular plane (IMPA), which should be 90°, and the lower incisor to Frankfort horizontal (FMIA), which should be 65-70°, relating the mandibular dentition to the cranial base. In this analysis, the mandibular plane is defined as a line tangent to the most prominent points on the lower border of the mandible. The original FH was based on Po located 4.5mm above the geometric centre of the ear rod, however the Tweed society has now adopted machine porion to be at the superior extent of the radiopague ear rod marker.

The original analysis was modified by Merrifield (1966) and now comprises a number of additional measurements borrowed from other analyses to describe the maxilla-mandibular relationship [SNA/SNB/ANB (Steiner, 1953), AO-BO (Jacobson, 1975)] and vertical relations [Occlusal plane (Downs, 1948)]. A variation of face height ratio (called the Index post/ant or the Tweed Face height ratio), originally developed by

Bjork (1947) is also included. This ratio is the posterior face height divided by the anterior facial height and provides a guide of complexity and difficulty in correction. A soft tissue analysis incorporating the Z angle, upper lip thickness and, total chin thickness has also been incorporated. An ideal soft tissue profile should allow the total chin thickness to be equal or slightly greater than upper lip thickness; the upper lip should be tangent to the profile line with the lower lip either tangent or slightly behind the profile line and; with normal FMA, IMPA, FMIA and ANB measurements in the adult and adolescent, the normal Z angle should approximate 90° and 78° respectively.

While this analysis provides a simple clinical guide to assess lip/chin relationships and considers growing and mature patients, the normative sample is heavily biased to females. One major disadvantage is that it relies on the accuracy of FH as an indicator of natural head position.

THE SASSOUNI ANALYSIS

The Sassouni analysis (1955, 1969) is an archial analysis and one of the first to consider the dentofacial complex as a whole within the individual pattern. Sassouni proposed the use of the optic plane as a substitute for FH, and was the first to emphasis vertical as well as horizontal relationships using Lo-Lo on the frontal cephalometric radiograph as a reference in conjunction with the lateral radiograph.

The sample basis of this analysis were 100 Caucasian children aged 7 to 15 years (51 females/49 males) of principally Mediterranean origin. This analysis has some points and lines not previously described on the lateral radiograph including Si, Sp, Te, the supraorbital plane, parallel to supraorbital, the infraorbital plane, the Optic plane and, point O. On the frontal radiograph points and lines used to assess vertical symmetry include Lo-Lo and, Lo-Mx. The Sassouni analysis also incorporates a number of arcs with "O" being the centre including; The Anterior arc from N; Basal arc from point A; Midface arc from Te and; the Posterior arc from Sp.

The analysis involves the visual assessment tendencies indicative of the well proportioned face including: convergence of the parallel to supraorbital line, palatal plane, occlusal and mandibular planes toward a point (O); the anterior arc should pass through ANS, the tip of the maxillary incisor, and pogonion, while the basal arch from point A should pass through point B, permitting the evaluation of the position of the mandibular apical base. The mid facial arc, indicative of the position of the first molars, should pass from Te tangent to the mesial surface of the maxillary first molar when ANS is on the anterior arc. The posterior arch, indicative of the posterior position of the mandible, should pass through Go.

Vertically, upper and lower face heights should be equal, both anteriorly and posteriorly. GoPog should be equal in size to the cranial base (from Sp to N along the radius), extending between the anterior and posterior arcs. The cranial base plane to palatal plane angle should also be equal to the palatomandibular angle. Lo-Lo and Lo-Mx on the left and right sides are used to identify vertical and horizontal asymmetry.

This analysis provides a rapid, simple and convenient analytical method, despite the fact that the positioning of O can sometimes be difficult. Unfortunately the application of this system, particularly the dental analysis, to groups other than represented by the normative sample may not be valid. While the analysis is the first to attempt a third dimension, the frontal analysis is solely based upon the use of a single reference line.

THE BJORK ANALYSIS (JARABAK ANALYSIS)

The Bjork analysis (Bjork, 1947, 1963) evolved from a study to examine the mechanics of prognathism and the relationship between facial build and bite in two representative Swedish populations; a group of 322 orthodontically untreated Swedish 12 year old boys with good dental condition and, 281 Swedish conscripts, 21 to 23 years of age.

The primary reference plane is the SN plane, and is divided into an anterior and posterior cranial base by the S-Articulare plane. This was the first analysis to take into account the influence of cranial base on facial structure. Bjork re-named a number of existing points including SP (Spinal Point = ANS), SS (Subspinal point = A point), PR (Prosthion), SM (Supramental point = B point), ID (Infradentale), SNP (Spinal Nasalis Posterior = PNS), Is (incision superius), Ii (incision inferius) and introduced a number of new cephalometric points including: DD (The most prominent point of the chin in the direction of each line of measurement determined by the point of intersection between a tangent to the base of the mandible and a line tangent to ID; GN - Gnathion [The deepest (lowest and most inward) point on the chin. This is not the standard definition and is equivalent to standard Menton (Me)] and; KK (the point of intersection between tangents to the base and the ramus of the mandible).

More significantly Bjork contributed a number of planes comprising the "Bjork polygon", formed by connecting the points N-S-Ar-Go-Gn, and applied his findings to treatment planning and growth. The basis of this approach is the relationship of three angles - saddle angle (N-S-Ar), articular angle (S-Ar-Go), and gonial angle (Ar-Go-Me) - and the lengths of the sides of the polygon. The saddle angle determines the flexure or bend between the anterior and posterior cranial base and is influenced by the spheno-occipital synchrondrosis. The posterior cranial base influences the degree of inferior and posterior growth of the articular fossae and is therefore is important when considering the direction of the growth. Posterior facial height, determined by the length of posterior cranial base is equally important. The mandible, via mandibular ramus length, is related to the cranial base or more specifically, the posterior cranial base, by the articular angle. A large articular angle decreases facial prognathism, making the face more retrognathic, whereas a small articular angle makes the face more prognathic.

Gonial angle is divided into two parts by a facial depth line from N thorough a tangent to the lower border of the mandible and a tangent to the posterior surface from the ascending ramus Gonion. Large upper angles indicate remaining growth increment will be more forward and make the lower face more prognathic.

Interpretation of the polygon allows many inferences about the possible nature of the facial growth.

The sum of the angles N-S-A-Go = $396 \pm 6°$: Less than this indicates a counter clockwise growth rotation, a horizontal pattern; more indicates a clockwise or vertical growth rotation. The anterior cranial length should be the same as the distance as the lower line of the polygon; a long mandible indicates mandibular prognathism. The Ant/Post ratio i.e. ratio of posterior face height to anterior face height should be 62%. A value below the mean indicates a backward divergence while those above have greater growth increment in posterior than in anterior facial height.

The Jarabak analysis is a hybrid of many analyses and based on Bjorks sample together with 200 orthodontically treated patients (Jarabak and Fizzell, 1972). While the complete analysis has additional points and measurements to locate the dental bases and dentition, the important contribution is the interpretation of the Bjork polygon for determination of growth. Increments per year for each of the segments of the polygon are provided for males and females from 15 to 18 years. Growth direction is also attempted by dividing the gonial angle.

Bjorks' facial diagram provides the linear and angular configurations that determine the amount of facial prognathism and can serve as a template for quick visual assessment. Unfortunately the analysis is purely sagittal with no soft tissue analysis and normative values confined to Swedish males. Jarabeks and Fizzells' analysis highlights the use of cephalometrics in the assessment of dental, skeletal and soft tissue profile and while no mention is made of race or proportions of male and female patients sampled, it does provide a guide to growth prediction, albeit limited to orthodontically treated patients 11 to 18 years of age.

THE HARVOLD ANALYSIS

Harvolds' analysis (1974) is a skeletal analysis intended to demonstrate changes in the maxilla and mandible resulting from "functional appliance" wear based on a Caucasian sample from the Burlington study. Mean values are age and gender related and comprise the norms on which the software program Dento-Facial Planner (Dentofacial Software, Toronto, Canada) are derived. No reference planes were used. Length and height dimensions are projected on the midsagittal plane and related to a radial system with the centre at the temporomandibular joint. The length of the maxilla is measured from TMJ point (the posterior wall of the glenoid fossa) to lower ANS, (the point on the lower shadow of ANS where it is 3mm thick). Mandibular length is measured from TMJ point to prognathion (PGN), the point on the bony chin giving maximum length from the TMJ point. The vertical relationship is assessed by the lower face height (from ANS to menton).

The original work does contain an analysis of relative dental position by use of the incisor line (a line drawn through the apices of the maxillary and mandibular central incisors) however this is not often used due to the difficulty in locating the specific landmarks involved. This measure is very similar to the Witts analysis from which it was modified. The "functional classification" of the occlusion is related to the posterior angle the central incisor line forms to the occlusal plane: Class I (an ideal occlusion) = 89°; Class II > 95° and; Class III < 84°.

The analysis is simple and quick to perform, with norms changing to reflect growth. Within the limitations of the establishment of the cant of the occlusal plane, the incisal line is a quick indicator of functional classification. The analysis is limited because it only measures mandibular and maxillary length and the lower face and is not related to the cranial base, has no soft tissue analysis, and is highly dependent on visualization of the TMJ.

RICKETTS BIOPROGRESSIVE

The Rickets Bioprogressive analysis (1957, 1960a, b) is a treatment technique whereby growth and development are taken into account to locate, evaluate or assess areas of skeletal dysplasia; to identify areas within the maxillofacial complex treatable by

conventional means and; to identify those components of the face which may influence treatment. Ricketts' sample of over 1000 treated and non-treated cases was accumulated from three studies. The main horizontal reference plane is FH, with NBa used supplementarily.

Ricketts analysis introduces a number of new landmarks including CC and CF (key points of superimposition), DC, PM, and constructed points Gn, Go and, Xi as well as the concept of oral "gnomon": an angular configuration of bony components that don't alter position with treatment or growth. These include lower face height, facial axis angle, and maxillary depth. As Ricketts normative values change with age, his analysis can be used to make growth predictions (including treatment effects), i.e. provide a "VTO" or Visual Treatment Objective. Ricketts functional occlusal plane and mandibular plane differ from previous analyses.

The analysis is divided into six fields (I to VI): Denture; Skeletal; Denture base to skeletal; Aesthetic problems; cranial and; Internal structures. The cranial base has an important role on overall facial form and is described by cranial deflection and anterior cranial length. The maxillary orthopedic relation is defined by its relationship to the mandible by convexity and to the FH by maxillary depth. The relative horizontal dimension of the maxilla can also be quantified with the use of intermaxillary measurements such as PNS to ANS. The mandibular position is defined by its relationship to FH (facial angle and depth) and the cranial base (Po location and ramus position). The relative horizontal and vertical dimensions of the mandible can also be quantified with the use of measurements such as corpus length, ramus Xi position, mandibular length, mandibular body length and ramus height.

The anterior maxillary dentition is related to the mandibular dentition by the interincisal angle. Other measures of malocclusion include incisor overjet, incisor overbite, and L1 to occlusal plane. Posterior horizontal relationships can be classified in the molar and canine regions. The teeth can be related to their respective jaws or to each other. The maxillary dentition is related to the mandible by linear and angular measurements of U1 to APog , maxillary incisor inclination and the position of the upper molar (U6 to PTV). A key aesthetic as well as functional objective in the mandible is the establishment of the mandibular incisor protrusion measured linearly and angularly (L1 to APog).

The vertical position of the maxilla can be assessed by the maxillary height whereas the mandible is usually described with respect to the cranial base (FH) by the mandibular plane angle. Other parameters which assist in the assessment of vertical discrepancies in the mandible include facial taper, the occlusal plane to ramus and occlusal plane inclination. Overall measures of growth include the facial axis, lower face height, posterior facial height and, mandibular arc. Finally skeleto-dental soft tissue facial esthetic assessment includes lip protrusion, upper lip length and lip embrasure to functional occlusal plane angle.

This analysis is four dimensional and can be applied to individuals for assessment of their independent characteristics rather than their comparison to one standard. The major weakness with this analysis are the unspecified and uncontrolled sample providing the normative data for many of the measurements. The variability of the location of certain landmarks such as Pt, Xi and Pm also limit the analyses usefulness.

OTHER ANALYSES

Many other cephalometric analyses have been introduced into the orthodontic literature. Each have their own merit in their use or in correlation to check other measurements.

The Wits appraisal (Jacobson, 1975)) relates the linear distance from perpendiculars dropped from points A and B onto the occlusal plane and measures the anteroposterior discrepancy of the jaws relative to each other and is independent of the cranial base. It is an excellent check on the ANB.

McNamara's analysis (McNamara, 1984), derived from the work of Ricketts, Harvold and others is truly unique in that he used a perpendicular line from Frankfort horizontal with one axis through N to determine the position of the skeletal and dental components. The analysis includes a number of linear comparisons to describe the maxillary dentition to the maxilla (N perpendicular to A perpendicular), relate the maxilla to the cranial base, and to describe chin position (Pog to N perpendicular). The analysis made no provision for quantifying the cranial base shape or form. The normative sample is derived from three sample groups including those of the Bolton, Burlington and Ann Arbor studies to create composite norms. Facial height percentages, calculated by dividing upper face height and lower face height (ANS to Me) by total face height, are often used as reliable indices for facial aesthetics, however other measurements must also be considered to determine which component is at fault.

The soft tissue outline, especially important in orthognathic surgery can be readily assessed using the Holdaway Ratio (Holdaway, 1956), a 1:1 ratio between the lower incisor and pogonion to NB. The nasolabial angle which attempts to measures the nose-to-upper-lip relationship has been criticized as too variable to be of any diagnostic value. The most comprehensive soft tissue analysis is the Legan Analysis (Legan and Burstone, 1980), a companion to the COGS analysis (Burstone *et al.*, 1979) for orthognathic surgery. The analysis is divided into two sections: facial form and lip form. Facial form is described by facial convexity, maxillary and mandibular prognathism, vertical height and lower vertical height to depth ratios as well as lower face to throat angle. Lip position and form is assessed by the nasolabial angle, upper and lower lip protrusion and vertical lip to chin ratio.

CHOOSING AN ANALYSIS

The initial interpretation of a cephalometric radiograph involves the visual assessment of a number of planes, mostly in accordance with Saussoni's analysis. The FH and palatal plane should be parallel and are indicative of skeletal bite tendencies. ANB angle can be used to roughly estimate the skeletal classification. The palatal plane to C1 relationship may indicate maxillary dental anomalies as a result of digital habit. Together with overbite, overjet, interincisal angle, tooth position and eruption, the Curve of Spee and the long axis of the U1 to Or, the dental component of the patient can be quickly assessed. The mandibular plane to occipital bone relationship provides some indication of mandibular growth. Lower incisor apex should rest in the symphysis equally between the labial and lingual cortical plate and its long axis should form 90° with the lower border of the mandible.

The relative dimensions of a number of structures can provide some initial information on an individuals growth tendancy. The pterygomaxillary fissure size is short and wide in horizontal growers and long and thin in vertical growers. Symphysis size is small and thin in vertical growers, large and wide

in horizontal growers. Antegonial notching can be pronounced in vertical growers and diminished in horizontal growers.

Unfortunately there is not a single numeric analysis that is applicable to every patient. While Ricketts provides extensive information, other specific measurements should be considered. As a starting point Downs original analysis provides a comprehensive division of skeletal and dental criteria providing a clinically useful, thorough and organized scheme for cephalometric assessment. Overall skeletal proportions can be initially assessed using Bjorks facial polygon. Sagittally, maxillary and mandibular relationships are adequately described by Ricketts while the Steiner analysis provides added information on the position of the maxillary and mandibular teeth to their respective dental bases. The mandibles' effect on antero-posterior discrepancies can be assessed by the Wylie analysis (Wylie, 1947, 1952), while skeletal vertical relationships can be assessed based on the convergence of specific planes (Sassouni, 1955) or more specifically by proportionate analysis (e.g. Coben, 1955). In soft tissue assessment, the Holdaway ratio and H-angle (Holdaway, 1956), E-line (Ricketts, 1957), Z-angle (Merrifield, 1966), Steiner (1959) and Riedel (1952) planes and angle of convexity (Legan and Burstone, 1980) are all useful measurements. Arnett and Burgman (1993a, b) provide useful guidelines for the analysis of 19 facial traits in 3 planes.

EVALUATION OF GROWTH

Serial Superimposition

One of the most useful clinical cephalometric procedures involves the assessment of dentofacial change resulting as a consequence of treatment or growth by comparison of linear and angular measurements or the superimposition of serial before and after cephalometric tracings. Numeric comparison is difficult and may not accurately reflect the positional and spatial changes between specific landmarks. Cephalogram superimposition, particularly considering specific regions individually, provides a visual and relatively easy method to compare quantitative and qualitative morphological changes. The suggested color code for consecutive cephalograms (ABO, 1992) is pretreatment (black), progress (blue), and of treatment (red) and, retention (green).

A number of superimposition reference planes have been suggested to evaluate overall facial development including the Broadbent triangle (Broadbent, 1931), SN with registration at Sella (ABO, 1992), Basion Horizontal (Coben, 1955) and BaN at CC point (Ricketts, 1957). Nelson (1960) recommends the use of the midpoint between the right and left shadows of the anterior curvatures of the greater wings of sphenoid where they intersect the planum as the most reproducible and valid method as these surfaces are the most stable during the growth period.

A number of techniques have been proposed to evaluate the movement of the teeth in relation to the basal maxillary components. Palatal superimposition methods may involve the ANS (Ricketts, 1960a) McNamara, 1981), pterygomaxillary fissure (Moore, 1959), infratemporal fossa (Riedel, 1974) whereas Downs (1948) proposed superimposition of the nasal floors at the anterior surface of the maxilla and Coben (1986) registers the maxilla at Ptm, maintaining Basion Horizontal. While McNamara (1981) uses superimposition on the best fit of the internal palatal structures, Bjork and Skieller (1977) use a structural method of superimposing the anterior surface of the zygomatic

process of the maxilla. A number of areas for superimposition have been proposed for the mandible including the lower border of the mandible or its tangent and constructed mandibular plane (Me-Go), however Bjork (1963) and Bjork and Skieller (1983) suggest that the anterior contour of the chin, inner contour and distinct trabeculae of the inferior border of the symphysis and posterior contour of the mandibular canal are the most stable structures. Both mandibular and condylar growth can be assessed from identification of these points and superimposition of progress or post-treatment cephalograms. Mandibular rotation can be evaluated by changes in N-S.

Hand-Wrist Radiographs

Fixed appliance orthodontic and orthopeadic therapy often relies on influencing the growth of either the maxilla, mandible or both to influence the differential growth patterns of these elements during treatment. Successful treatment demands precise timing and sequencing of therapy to pubertal cranial skeletal changes. Skeletal maturity via recognition of specific radiographic indicators is a commonly used measure of development. The hand wrist radiograph provides a relatively easily acquired radiograph for this assessment although not entirely reliable as a predictor of pubertal changes.

Their are principally two methods of skeletal maturation assessment using hand-wrist radiographs: The atlas and analysis methods.

The Greulich and Pyle (1959) atlas is by far the most comprehensive of the atlas methods. Their atlas displays two series (one male and the other female) of hand-wrist radiographs across 30 stages from newborn to 19 years. Each film was assigned a bone age equal to the subjects chronological age at the time of exposure. Ossification centers of the individual are compared with radiographs in the atlas until a standard is identified that most closely approximates the pattern of that individual. The skeletal age of that standard is then assigned to the patient. Experienced examiners agree with themselves and each other to within 0.8 years on 95% of cases. The technique is simple when there is a perfect match however it is highly subjective and based upon norms obtained on children in the 1930's and 40's of high socioeconomic level who matured rapidly even by today's standards. The bone age assigned may therefore not be relevant to previous or future generations. There is rarely a match with any of the standards because there are differences in the relative maturation rates of each bone.

Tanner *et al.*, (1975) developed a technique which is currently recommended for use by most medical radiologists known as the TW2 (Tanner-Whitehouse) method. The bones of the hand and wrist are assigned numeric scores based on their individual levels of maturity. Their are 20 centers of ossification and 8 or 9 (depending on the bone) levels of maturity, designated from A to I. The maturity levels correspond to numerical scores, which are added, resulting in a maturity level which can range from 1 to 100. This can be plotted on a chart portraying means and percentiles of maturity scores of children at various ages. The approach involves assessment of the radius, ulna and short bones of the fingers (RUS), omitting the second and fourth digits, and the carpal bones, omitting the pisiform. The overall score is achieved by calculating the combined score of 1/2 the carpal score plus 1/2 RUS. This chart can be used to determine percentile maturity relative to other children of the same age or to assign a "bone age". This technique is more reliable and less subjective than the Greulich and Pyle. Taranger *et al.*, (1976) introduced a modification of this technique which takes into

account the bones which have completely ossified or have not yet begun to ossify.

By far the most clinically applicable and orthodontically relevant method for skeletal maturity assessment is that developed by Fishman (1982) (Figure 5). This analysis uses four stages of bone maturation at six anatomical sites to determine up to eleven skeletal maturation indicators (SMI). The anatomic sites include the thumb, third and fifth finger and radius, while the stages of maturation related to the SMIs are that the width of the epiphysis is as wide as the diaphysis (SMI 1-3), ossification of the

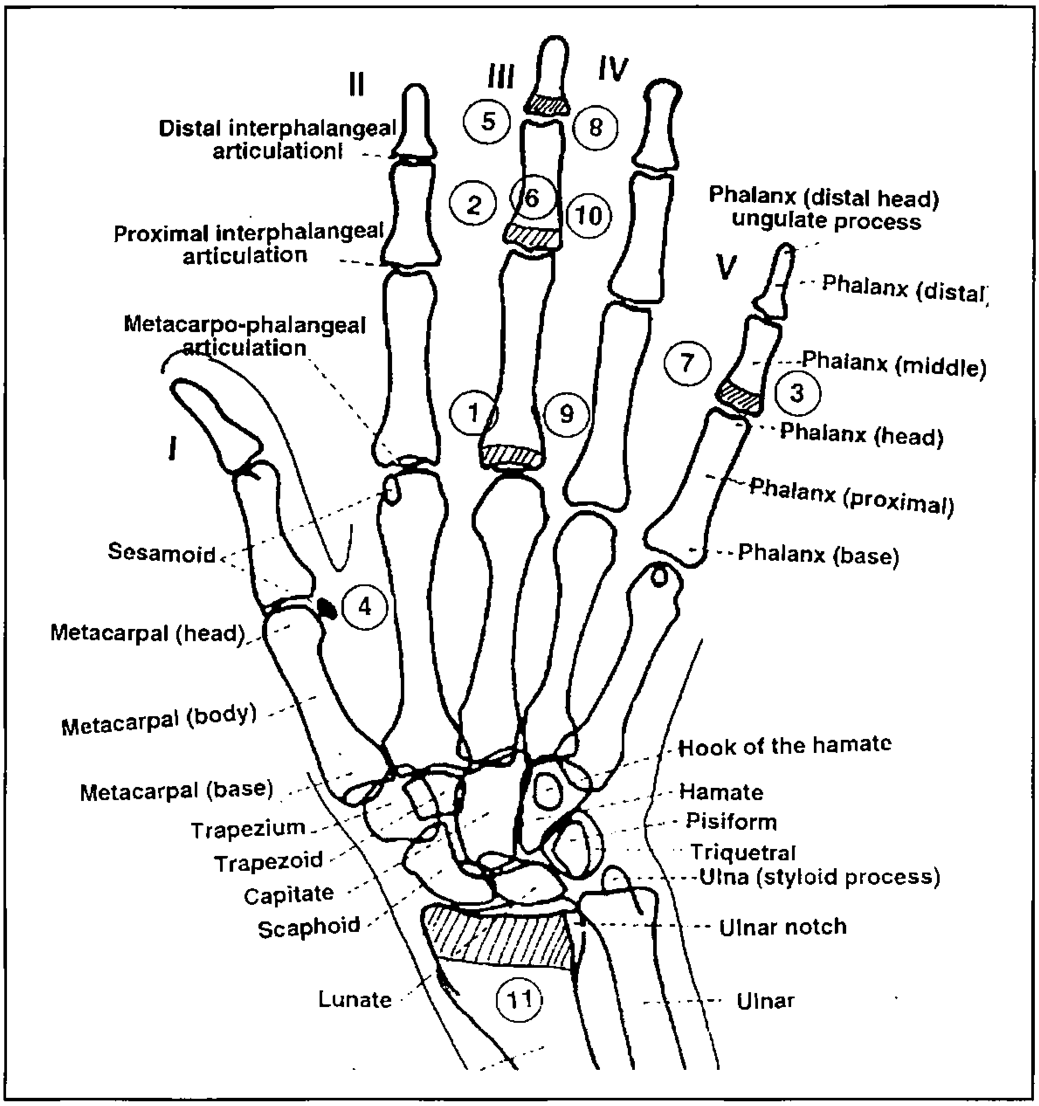


Fig. 5. Bones and articulations of the hand and wrist. Digits are numbered i to v. SMI numbers: (1) Width - Prox. phalanx iii; (2) Width - Middle phalanx iii; (3) Width - Middle phalanx v; (4) Ossification - Sesamoid i; (5) Capping - Distal phalanx iii; (6) Capping - Middle phalanx iii; (7) Capping - Middle phalanx v; (8) Fusion - Distal phalanx iii; (9) Fusion - Prox. phalanx iii; (10) Fusion - Middle phalanx iii; (11) Fusion - Radius

sesamoid (SMI 4), capping of the epiphysis (SMI 5-8) and fusion of the epiphysis with the diaphysis (SMI 9-11). These stages can be referred to a chart correlating the finding with chronologic age to determine skeletal maturity. Additionally SMI 1-5 occur during the period of greatest growth velocity, while SMI 6-11 signal the decline of growth velocity (Figure 6). Fishman has also related maturational development to percentages of total facial adult growth, to produce Maturational Prediction Matrices (MPM) estimating future growth by integrating percentages of completed growth and incremental skeletal changes.

COMPUTER ASSISTED ANALYSIS

Many orthodontists now use computers to assist them in the data acquisition and management components of cephalometrics. The efficiency, reliability and accuracy of diagnostic, prognostic and treatment evaluation phases of orthodontics can be greatly enhanced by digitally registering patient cephalograms. Additional benefits include the ease of storage and retrieval of cephalometric values and tracings, and potential integration of cephalometric with other clinical data including photographs and study models. While individual growth prediction assessments are still limited, surgical treatment objectives are facilitated in orthognathic patients.

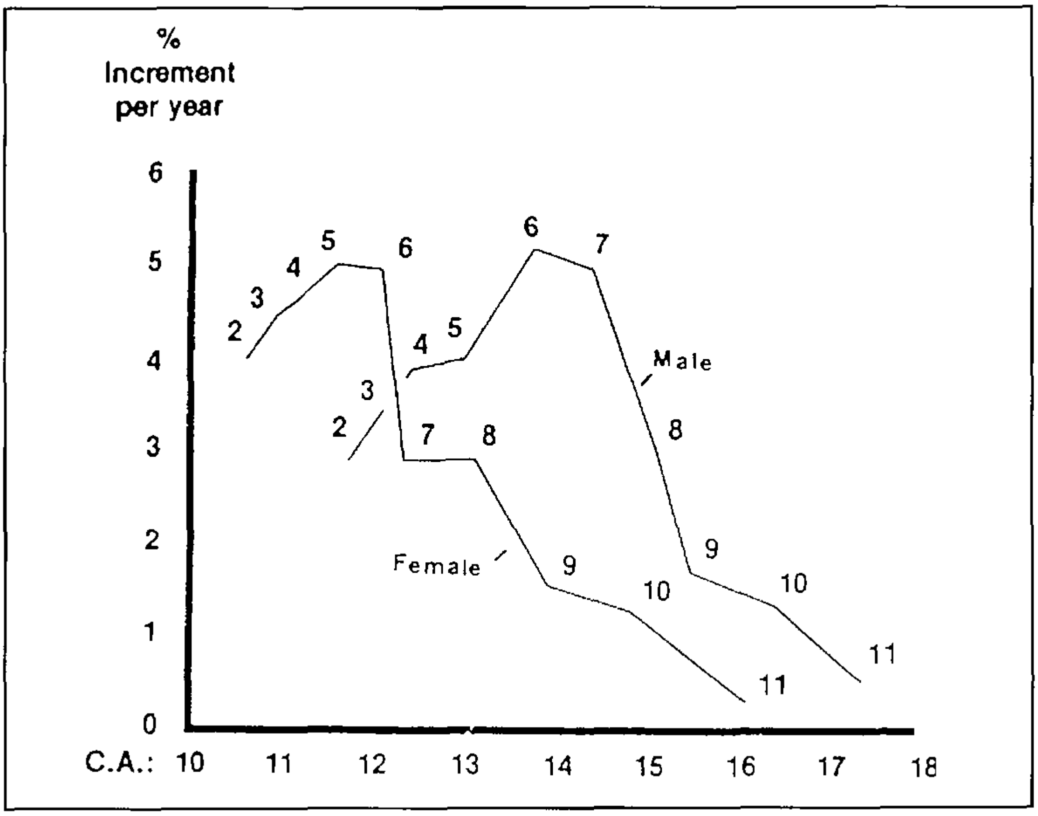


Fig. 6 Relative statural growth rate for females and males for SMI 2 to 11 vs. chronological age (C.A.). (Courtesy Dr. LS Fishman, Syracuse, NY).

Specific hardware requirements for computer applications in orthodontics include a digitizer, for landmark coordinate input, a computer and cathode ray tube monitor for display, analysis and manipulation software and a graphics plotter for producing overlays or hard copies. A number of software applications are available including JOE (Jiffy Orthodontic Evaluation; Rocky Mountain Orthodontics, Denver, CO), PorDios (Purpose On Request Digitizer Input Output System; Institute of Orthodontic Computer Sciences, Aarhus, Denmark), Dentofacial Planner (Dentofacial Software, Toronto, Canada) and DigiGraph (Dolphin Imaging Systems, Valencia, CA) for IBM based computers and Quick Ceph (Orthodontic Processing, Chila Vista, CA) for Macintosh computers. The ideal system should be capable of both static and dynamic functions including displaying X and Y coordinates of specific cephalometric landmarks, computing distances between each point, measuring angles between particular planes and perpendicular distances between points and planes. A specific plot should then be able to be analyzed using a variety of analyses or by a customized analysis. Specific age and gender normative data should also be able to be retrieved and compared with individual patient measurements. Multiple cephalograms should be able to be performed and superimposed using a variety of reference points or planes. While software is available providing numerically based diagnosis and specific orthopeadic and orthodontic planning, the validity of these features are, at this juncture, scientifically unfounded. Dynamic functions include VTO or STO generation and growth estimation. Soft tissue profile changes, particularly with STO should also be possible. Currently there is no evidence that computer assisted VTOs are any more reliable than manually derived estimates.

VISUALIZED TREATMENT OBJECTIVE

The visualized treatment objective (VTO) is an individual visual treatment goal derived from lateral cephalograms. Final "Post-treatment" or "growth" cephalograms are constructed from an established prediction of changes in the maxillofacial skeleton and soft tissue due to growth or orthopedic and dental alterations due to treatment mechanics. The VTO is clinically the most important use of the cephalogram as it may provide information for extraction decisions and on treatment mechanics necessary to effect a desired facial profile. VTO techniques involve the use of normative values to calculate expected changes in the position of lines or points on the original cephalogram and produce a final cephalogram which can then be superimposed on the original radiograph to demonstrate changes.

Holdaway first coined the term "VTO" and suggested that the growth of the craniofacial skeleton is predicted on derived incremental norms and that the soft tissue profile between the nose and chin, arranged within established ratios, may provide the balanced facial profile for a particular individual. Dental components should then be repositioned to an unstrained position of the maxillary lip relative to A-Po. He based mid face growth predictions on changes relative to SN or the anterior cranial base, while mandibular and vertical predictions are achieved using Downs' "Y" axis. Vertical position of the maxilla is established by using NA and assuming growth of the face being divided into thirds from N to Me, with the occlusal plane being midway between the maxilla and mandible. Holdaway proposes a number of sequential incremental growth modifications to the existing cephalometric to provide VTO. These steps include:

1) A 0.75mm/year growth along SN (designated x).

2) A 3x vertical growth of the mandible along the Y-axis, parallel to SN.
3) A compensatory horizontal mandibular growth allowing retention of Sella in the vertical dimension.
4) Repositioning of A point in relation to NA, maintaining a constant 40:60 ratio of growth above SN to growth below the mandible
5) The relocation of occlusal plane along NA to bisect the inter maxillo-mandibular distance
6) Soft tissue considerations involving the dentition - In the maxilla this implies maintaining a soft tissue/hard tissue point A thickness relationship, incorporating a mean 5mm lip contour between soft tissue A and "H" line, relocation of the maxillary incisors, eliminating lip strain and accounting for relapse (1.5mm), such that lip thickness anterior to the incisors is within 1 mm of the tissue thickness of tissue anterior to A point. In the mandible this involves repositioning the lower incisors to be in ideal occlusion with the maxillary teeth and calculating the amount of arch length required for this movement (2 x amount of lingual movement of the dentition from original to VTO position).
7) Finally the lower first molar is repositioned considering the arch length discrepancy. If the discrepancy is large (> 3.5mm) extractions may be indicated.

Ricketts' VTO method (1960a,b) has been highly popularized by Rocky Mountain Data Systems. This method involves a number of stages and five progressive superimpositions to assess the effect of growth.

Change due to normal growth of the cranial base (BaN) is calculated by increasing the linear position of N and Ba by 1mm/yr and anteriorly positioning new BaN along condylar axis approximately 1mm/yr. As Ricketts purports that facial axis does not change with growth, mandibular growth is achieved by translating the mandible along the corpus axis approximately 2mm/yr. Facial axis change and chin growth can then be assessed by superimposition of the original tracing along BaN at point CC.

Maxillary growth is considered dependent upon the positions of the palatal plane and A point. The former is estimated inferiorly as being approximately one third the total height increase while the latter is positioned inferiorly 0.5mm for every 1mm of posterior displacement. Maxillary change and A point change can then be assessed by superimposition of the original tracing along BaN at point CC.

The new occlusal plane is constructed by translating the occlusal plane one third the total height increase, along and perpendicular to new APog . The lower incisor and remaining dentition are then positioned with respect to the tip of the lower incisor which is located 1mm above the occlusal plane and 1mm ahead of APog plane. Changes in lower incisor and mandibular position as well as evaluation of anchorage requirements can then be assessed by superimposition of the original tracing along the corpus axis at point PM.

Upper molar and incisor teeth are then traced using a template in Class I position. These effects can be assessed using superimposition of the original tracing along the palatal plane at ANS.

Finally soft tissue profile is established by superimposition of ANS along palatal plane in four stages; The tip of the nose is advanced about 1mm per year; A' to A point and B' to B point relationship remain unaltered however the contour of the upper lip increases

in thickness 1mm for every 3mm of retraction; the lower lip thickens very little and; chin soft tissue increases slightly, particularly if lip strain is reduced or the chin is elevated. These effects can be assessed using superimposition of the original aesthetic plane tracing at the crossing of the occlusal plane.

Both methods are time consuming and demand meticulous superimposition and tracing technique and are usually reserved for orthognathic patients.

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7 The Mixed Dentition

John P Fricker

INTRODUCTION

The mixed dentition is that period of dental development starting with the eruption of the first permanent molars and ending with the complete replacement of all deciduous teeth. The average time period for this phase is six to eight years and is coincident with rapid growth and development of the craniofacial skeleton. The primary aims of mixed dentition treatment are to correct dental arch irregularities, occlusal and jaw relation abnormalities and to eliminate functional interferences. These may be classified as preventive or interceptive. *Preventive* applies to the elimination of factors that may lead to malocclusion in an otherwise normally developing dentition. *Interceptive* implies that corrective measures may be necessary to prevent a potential irregularity from progressing into a more severe malocclusion. It is essential to have a sound understanding of the time sequence in the development of the child's dentition and the ability to recognise the rate and direction of the general physical maturation of the child. Many cases of apparent malocclusion in the mixed dentition are actually part of the normal process of dental development. Incisor irregularities, spacing and apparent ectopic eruption of teeth may present early in the mixed dentition yet self correct with growth and development. Neither the appliances used nor the treatment itself should interfere with the often rapid changes in eruption of permanent teeth and the dynamic nature of occlusal adjustment. (See chapter 2, Development of Dentition).

Indications for Treatment

- Crowding
- Space opening or regaining
- Digit sucking
- Missing teeth
  - congenital absence
  - traumatic loss
- Elimination of supernumerary teeth
- Eruption of teeth
  - ectopic teeth
  - impaction
  - transposition, ankylosis
- Class II malocclusion
  - increased overbite
  - increased overjet
- Class III malocclusion
  - anterior crossbite
  - posterior crossbite

CROWDING

Mixed Dentition Analysis

The purpose of a mixed dentition analysis is to determine the space available in the dental arch for the permanent successors to erupt. To complete this analysis one must first record the arch perimeter length and the mesio distal widths of the mandibular permanent incisors.

The most accurate way to determine arch length is to measure directly from a set of study casts. Soft wire can be adapted from the mesial of the first permanent molar to follow the arch perimeter of the distal of the contra lateral second deciduous molar. The wire should be shaped to the ideal arch form and not follow any teeth out of alignment. Once the arch length has been determined, it is then necessary to estimate the space required for the permanent successors. There are two methods for this:

1. Direct measurement of unerupted teeth from radiographs with allowances for magnification
2. Determine the size of premolars and canines from the measurement of permanent teeth already in the arch

A Moyers prediction chart (Moyers, 1958) will indicate the level of confidence in predicting whether the space available is sufficient to accommodate the unerupted teeth. In this analysis the width of the mandibular permanent incisors measured and added. Using this value in the Moyers table, one can determine the percentage of cases the space available in the arch will be sufficient for tooth eruption. From the table, use the 75% level of prediction to show that for a given width of lower incisors, 75% of the population will have canine and premolar widths totalling "X". (Table 1).

There is a high correlation between the sizes of the permanent mandibular incisors and the combined sizes of premolars and permanent canines. Thus it is possible to forecast the amount of space required for the unerupted teeth and plan interceptive and or preventive space management requirements. Some types of occlusions require space maintenance more than others. For example if the distal surfaces of the opposing second deciduous molars end on the same vertical plane, there will be need for a greater amount of leeway space in the mandibular arch than where the distal surface of the second primary molars form a so-called "step" terminal plane. *(See chapter 2)*

a) Procedure in the Mandibular Arch

1. Measure with the tooth-measuring gauge (Table 1) or a pointed Boley gauge the greatest mesiodistal width of each of the 4 mandibular incisors. Record these values in the Mixed Dentition Analysis Form (Table 1).
2. Determine the amount of space needed for alignment of the incisors. Set the Boley gauge to a value equal to the sum of the widths of the left central incisor and left lateral incisor. Place one point of the gauge at the midline of the alveolar crest between the central incisors and let the other point lie along the line of the dental arch on the left side (Fig. XI-17). Mark on the tooth or the cast the precise point where the distal tip of the Boley gauge has touched. This point is where the distal surface of the lateral incisor will be when it has been aligned. Repeat this process for the right side of the arch. If the cephalometric evaluation shows the mandibular incisor to be too far labially (see Chap. XII). the Boley gauge tip is placed at the midline, but moved lingually a sufficient amount to simulate the expected uprighting of the incisors as dictated by the cephalometric evaluation.

MIXED DENTITION ANALYSIS

Patient ____________________ Age ____ years ____ months ____ Sex ____

Date __________ Address ____________________ Parent __________

Tooth Size

Upper

	Right	Left
Space left after alignment of 2 and 1		
Predicted size of 3 + 4 + 5		
Space left for molar adjustment		

Lower

	Right	Left
Space left after alignment of 2 and 1		
Predicted size of 3 + 4 + 5		
Space left for molar adjustment		

Remarks: Overjet ________________ Overbite ________________

Molar Relationship ______________________________

Remarks ______________________________

Table 1 Chart for recording data of the Mixed Dentition Analysis. The tooth sizes are inserted in the proper positions on the chart after measurements on the casts or in the mouth. The predicted size of the cuspids and premolars is taken from the 75% level of probability in the probability chart (Table 2)

3. Compute the amount of space available after incisor alignment. To do this step, measure the distance from the point marked in the line of the arch (step 2, above) to the mesial surface of the first permanent molar (Table 1). This distance is the space available for the cuspid and 2 premolars and for any necessary molar adjustment after the incisors have been aligned. Record the data for both sides on the Mixed Dentition Analysis Form.

Probability chart for predicting the sum of the widths of maxillary permanent canines and premolars from the lower permanent incisors.

Sum of incisor widths=	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
95%	21.6	21.8	22.1	22.4	22.7	22.9	23.2	23.5	23.8	24.0	24.3	24.6
85%	21.0	21.3	21.5	21.8	22.1	22.4	22.6	22.9	23.2	23.5	23.7	24.0
75%	20.6	20.9	21.2	21.5	21.8	22.0	22.3	22.6	22.9	23.1	23.4	23.7
65%	20.4	20.6	20.9	21.2	21.5	21.8	22.0	22.3	22.6	22.8	23.1	23.4
50%	20.0	20.3	20.6	20.8	21.1	21.4	21.7	21.9	22.2	22.5	22.8	23.0
35%	19.6	19.9	20.2	20.5	20.8	21.0	21.3	21.6	21.9	22.1	22.4	22.7
25%	19.4	19.7	19.9	20.2	20.5	20.8	21.0	21.3	21.6	21.9	22.1	22.4
15%	19.0	19.3	19.6	19.9	20.2	20.4	20.7	21.0	21.3	21.5	21.8	22.1
5%	18.5	18.8	19.0	19.3	19.6	19.9	20.1	20.4	20.7	21.0	21.2	21.5

Probability chart for predicting the sum of the widths of the lower permanent canines and premolars from the lower permanent incisors.

Sum of incisor widths=	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
95%	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.2	23.5	23.8	24.1	24.4
85%	20.5	20.8	21.1	21.4	21.7	22.0	22.3	22.6	22.9	23.2	23.5	23.8
75%	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1	23.4
65%	19.8	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2	22.5	22.8	23.1
50%	19.4	19.7	20.0	20.3	20.6	20.9	21.2	21.5	21.8	22.1	22.4	22.7
35%	19.0	19.3	19.6	19.9	20.2	20.5	20.8	21.1	21.4	21.7	22.0	22.3
25%	18.7	19.0	19.3	19.6	19.9	20.2	20.5	20.8	21.1	21.4	21.7	22.0
15%	18.4	18.7	19.0	19.3	19.6	19.8	20.1	20.4	20.7	21.0	21.3	21.6
5%	17.7	18.0	18.3	18.6	18.9	19.2	19.5	19.8	20.1	20.4	20.7	21.0

Table 2 Probability charts for computing the size of unerupted cuspids and bicuspids. The top chart is for the upper arch. The bottom chart is for the lower arch. Measure and obtain the mesiodistal widths of the 4 permanent mandibular incisors and find that value in the top horizontal column. reading downward in the appropriate vertical column. obtain the values for expected width of the cuspids and premolars corresponding to the level of probability you wish to choose. Ordinarily, the 75% level of probability is used. Note that the mandibular incisors are used for the prediction of both the mandibular and maxillary cuspid and premolar widths. (Moyers, 1958)

4. Predict the size of the combined widths of the mandibular cuspid and premolars. This prediction is done by use of probability charts (Table 2). Locate at the top of the mandibular chart the value closest to the sum of the widths of the 4 mandibular incisors. Beneath the figure just located lies a column of figures indicating the range of values for all the cuspid and premolar sizes that will be found for incisors of the indicated size. For example, not that for incisors of 20.0mm. combined width the summated mandibular cuspid and premolar widths range from 22.6mm. at the 95% level of confidence down to 19.2mm. at the 5% level. This means that of all the people in the universe whose lower incisors measure 22.0mm, 95% will have cuspids and premolars whose widths total as low as 19.2 mm. No one figure can represent the precise cuspid-premolar sum for all people, since there is a range of posterior tooth widths seen even when the incisors are identical. The value at the 75% level is chosen as the estimate, since it has been found to be the most practical from a clinical standpoint. In this instance, it is 21.6mm., which means that three times out of four the cuspid and premolars will total 21.6mm. or less. Note also that only five times in a hundred will these teeth be more than 1mm. greater than the estimate chosen (21.6mm.). Theoretically, one should use the 50% level of probability, since any errors would then distribute equally both ways. However, clinically, we need more protection on the down side (crowding) than we do on the up side (spacing). Record this value in the proper blanks for right and left sides, since it is the same for both.

5. Compute the amount of space left in the arch for molar adjustment. This computation is done by subtracting the estimated cuspid and premolar size from the measured space available in the arch after alignment of the incisors. Record these values in the proper blanks on each side.

   From all the values now recorded, a complete assessment of the space situation in the mandible is possible.

b) Procedure in the Maxillary Arch

The procedure is similar to that for the lower arch, with two exceptions: (1) a different probability chart is used for predicting the upper cuspid and premolar sum (see Table 2) and (2) allowance must be made for overjet correction when measuring the space to be occupied by the aligned incisors. Remember that *lower* incisors' widths are used to predict upper cuspid and premolar widths.

Figure X1-20 illustrates the application of the Mixed Dentition Analysis to a specific clinical problem. Note that the localization of any space shortages helps greatly in selection of the space management appliance. Discussion of the treatment of space problems is found in Chapter 15.

It is good practice to study the periapical, lateral jaw or oblique cephalometric radiographs when the Mixed Dentition Analysis is done in order to note absence of permanent teeth, unusual malpositions of development or abnormalities of crown form. For example, mandibular second molars sometimes have two lingual cusps. When they are so formed, the crown is larger than might be expected from the probability chart and, therefore, a higher predictive value is used. One may, of course, measure the size of the crowns of the unerupted cuspid and premolars in periapical radiographs for supplemental information or corroboration of the Mixed Dentition Analysis estimate.

Robert E Moyers, Handbook of Orthodontics for the Student and General Practitioner. 3rd ed. 1958Pg. 372-378.

If the first permanent molars erupt in a cusp-to-cusp relationship, there is need for more mesial shifting of the mandibular first permanent molar and, therefore, a greater need for additional leeway space. Where the entire leeway space, regardless of its size, is needed to establish a proper intercuspation of first permanent molars, a space maintainer can be a valuable interceptive appliance if one or more of the deciduous molars is lost prematurely.

Other factors must be considered in deciding whether or not a space maintainer will be needed following the premature loss of deciduous molars. The tooth or teeth that are lost prematurely is an important consideration. The loss of one or more deciduous incisor teeth - maxillary or mandibular - is not nearly as detrimental to the development of normal occlusion as the loss of a deciduous first or second molar. When a deciduous incisor is lost, there is little, if any, tendency for the permanent first molars to drift mesially, when the deciduous first and second molars are still present and have adequate root structure to resist mesial movement of the permanent first molar.

Fig. 1. Premature loss of a mandibular left deciduous canine resulting in a midline shift to that side.

However, premature loss of a mandibular deciduous canine will allow the collapse of the incisal segment lingually with a midline shift to that side resulting in loss of arch length. *(Fig 1)* This can be very rapid, particularly where there is a strong muscle sling from the lower lip. Whenever a deciduous second molar is lost prematurely, whether before or after the eruption of the permanent first molar, there will be a loss of arch length due to the mesial drift of the permanent molar. *(Fig 2)* Thus where arch length is adequate prior to loss of a primary first or second molar a space maintainer should be fitted in order to preserve available space for the eruption of the premolars.

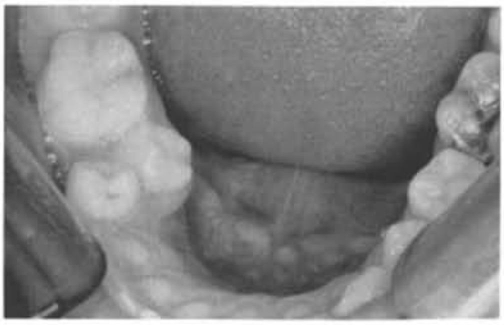


Fig. 2. Premature loss of a mandibular right deciduous second molar, resulting in mesial drift of the permanent first molar and lingual eruption of the second premolar.

SPACE-MAINTAINING DEVICES

The best space maintenance therapy is the preservation of the deciduous molars until natural exfoliation. While dental health education and improved caries prevention have lowered the number of children who develop malocclusion because of premature loss of deciduous teeth, it is still one of the most common controllable causes of malocclusion.

Types of Space Maintainers

There are two general types of space maintainers: fixed and removable. Fixed space maintainers may be fabricated from orthodontic bands and wire loop, cemented into place with a glass ionomer cement (Creath and Alexander, 1989). These appliances can provide long term space maintenance for up to two years, but should be checked at regualar intervals for looseness and marginal integrity. (*Fig* 3)

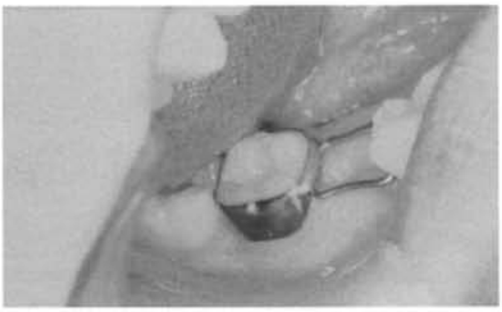


Fig. 3. Fixed band and loop space maintainer. The wire loop allows eruption of the premolar into the space.

Removable space maintainers have the shortcomings of all removable appliances: they demand the cooperation of the patient and they may be broken or lost when not worn. A removable space maintainer when worn during sleep only, is sufficient to hold space and prevent the mesial drift of the permanent molars. Night only wearing of the appliance also reduces the risk of loss or breakage by the patient. The appliance should be washed and inserted immediately before going to bed, then removed in the morning, washed and kept in a protective casing in a safe place.

Fabrication of Space Maintainers

The acrylic portion which covers the dental area may be built up to a level sufficient to limit the overeruption of the teeth in the opposing arch. Acrylic in this area may also be cut away when the tooth or teeth beneath the acrylic bridge begin to erupt. Thus, the appliance need not be completely discarded until the succeeding teeth are erupted a considerable distance and can maintain their own space. The wire extensions from the acrylic can still make contact with the teeth mesial and distal to the area being retained, even though the acrylic has been cut away.

REGAINING SPACE

When a deciduous second molar is lost prematurely due to caries or due to the ectopic eruption of the first permanent molar, the first permanent molar will drift mesially. This is most pronounced in the maxilla with a more rapid shift of the molar. The earlier the loss of the second deciduous molar and the less the root development of the permanent molar, the greater will be the amount of bodily mesial shift of the permanent molar. Thus the mechanics of space regaining or distal driving the permanent molar will vary accordingly.

Space regaining is most successful where there is a dental and skeletal Class I pattern with normal vertical proportions. Where there is a Class II or Class III pattern with deep overbite or open bite, it is likely that space loss is not a simple dento-alveolar problem.

Radiographs and study models are essential aids in assessing space needs. It is important to note whether teeth have moved bodily into the space or have tipped as tipping mechanics are much easier to control than bodily tooth movement. Radiographic examination should also locate the permanent second molars and establish space available for distalisation of first permanent molars.

Removable appliances are efficient in regaining spaces where uprighting of tilted permanent molars is required. The ACCO

appliance is such an appliance for uprighting maxillary first molars (*Figs 4A & 4B*) To maximise the anchorage, acrylic is flowed over the labial arch. This limits the amount of proclination of the incisors and directs the pressure of the spring onto the mesial of the first permanent molar.

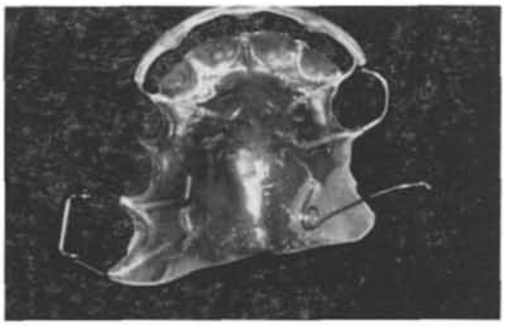


Fig. 4. A - ACCO appliance to regain space following mesial shift of a maxillary permanent molar.

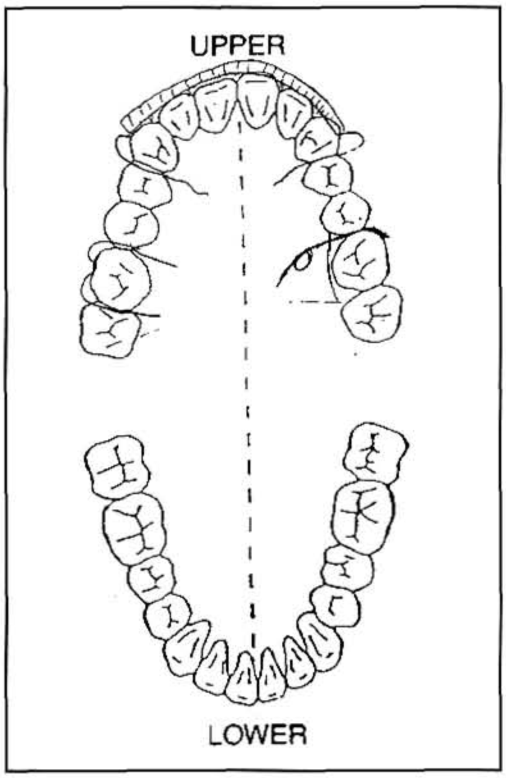


Fig. 4. B - Laboratory design for an ACCO appliance.

Thumb and Finger Sucking

One of the most common oral activities of the infant and young child is thumb and finger sucking. Sucking habits are perfectly normal in infancy. This reflex behaviour lasts for the first several months of postnatal life. It is an adaptive reflex common to mammals.

Because it is a normal activity, thumb and finger sucking may be ignored in infancy. Thumb or finger sucking that is discontinued by age 2 to 3 years produces no permanent malformation of the jaws or displacement of the teeth. If continued beyond the time that the permanent incisor teeth erupt, it is almost always a factor in producing malocclusion in the anterior portion of the mouth.

The typical malocclusion that results from prolonged thumb or finger sucking is characterised by an anterior open bite and protrusion of the upper incisor teeth. The lower incisor teeth may also be displaced lingually Protruding maxillary incisors and an anterior open bite favour the forward positioning of the tongue and a tongue thrust swallow pattern.

TREATMENT OF THUMB SUCKING

Chemical means

The chemical therapy employs either hot-tasting, bitter flavoured preparations or distasteful agents that are applied to the fingers or thumbs. Such things as cayenne pepper or quinine have been used to make the thumb or fingers so distasteful that the child will keep them out of his/her mouth. These preparations are effective with a limited number of children, and only when the habit is not firmly entrenched.

Mechanical means

A simple device for controlling thumb or finger sucking is the application of adhesive tape to the thumb or finger. In many instances this changes the character of the finger sufficiently

to call the child's attention to the fact that it is being placed in the mouth. Alternatively a Hawley appliance with a palatal bar may be fitted as a habit reminder. *(Figs 5 & 6)* This is important because in many instances thumb and finger sucking habits are at the subconscious level of the individual's attention. Even though there may be some desire on the part of the child to discontinue the act, he/she may find it difficult to do so unless made aware when they are sucking the thumb or finger.

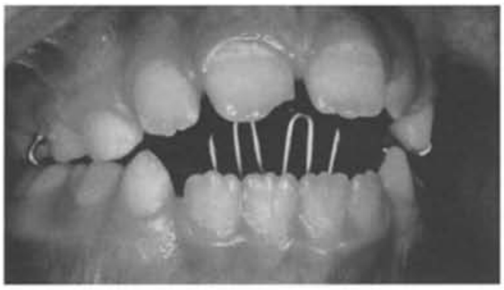


Fig. 5. Hawley appliance with palatal bar to restrict entry of the thumb and limit a tongue thrust.

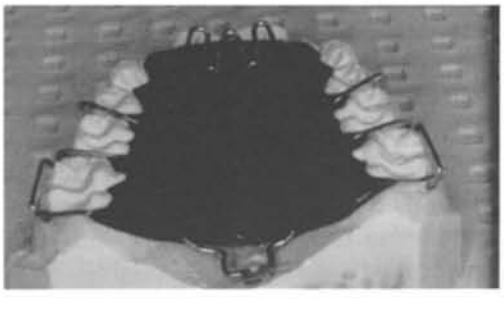


Fig. 6. The same appliance as figure 5 on the work model.

Often the child will respond to simple encouragement and explanation of the effect of digit sucking on the teeth. The child's own will to break the habit can react positively to such encouragement. As stated earlier, the critical time for the elimination of digit sucking is as the permanent incisors erupt. This generally coincides with entry into school where peer pressure can be a powerful influence to discontinuing the habit.

Congenitally absent teeth (*Oligodontia*)

Congenitally absent teeth are those teeth that have not developed from the tooth germ stage and occurs in approximately 4% of the population (Goodman *et al.*, 1994). The teeth most frequently congenitally absent are the mandibular and maxillary third molars, followed by the maxillary lateral incisors, the mandibular second premolars and the maxillary second premolars. *(Fig. 7A & B)*. Other teeth are occasionally absent, but the general trend is as per evolution where the last of the dental unit in each group of teeth is lost, such as fourth molars.

Oligontia is the term used where one or several teeth are congenitally absent with *anodontia* defined as the absence of all teeth. Both oligodontia and anodontia are inherited traits and are a significant diagnostic indicator of ectodermal dysplasia (Belanger, 1994). The congenital absence of a maxillary permanent central incisor is diagnostic of growth hormone deficiency and requires endocrine investigation.

An understanding of the normal sequence of eruption and average age of eruption of permanent teeth will alert the practitioner to the possibility of congenital absence. Any delay in the normal eruption time of permanent teeth or exfoliation of deciduous teeth, should be investigated radiographically. The panoramic film will provide the best view for investigation of premolars and molars but is often unclear in the incisor region due to the narrow focal trough. It may be necessary to supplement this with either periapical films or in the maxilla, a vertex occlusal film.

A radiographic survey at age 5 years will demonstrate the presence or absence of all permanent teeth except for third molars. Third molars do not normally present before the age of 9 years. A radiograph will show

the tooth sac before calcification begins and there is quite a range in development times for second premolars between the presentation of the dental sac and calcification of same.

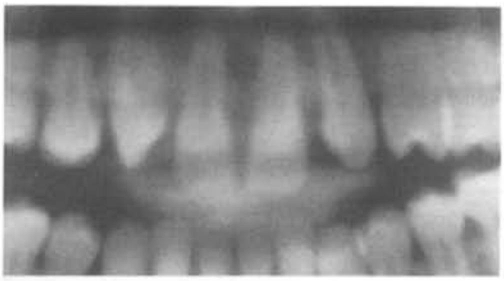


Fig. 7. A - Radiograph showing congenital absence of maxillary permanent lateral incisors.

B - Radiograph showing congenital absence of a mandibular second premolar.

Treatment

Where a permanent tooth is diagnosed as congenitally absent, there are two choices in management, either retain the space after loss of the deciduous tooth and insert a prosthetic replacement, or orthodontically close the space. Where premolars are absent the preferred method is the orthodontic closure of spaces. However where a maxillary lateral incisor or a central incisor is absent a decision on whether to open a space or close a space depends on the skeletal balance between maxilla and mandible (Bowden and Harrison, 1994).

A skeletal Class III pattern is one where the maxilla is smaller in proportion than the mandible and often there is a dental crossbite either anteriorly or posteriorly. Orthodontic correction will involve maxillary expansion and it is extremely difficult to close spaces in the maxillary anterior segment without constricting the maxillary dental arch. In these cases, prosthetic replacement of the absent incisor is the treatment of choice.

On the other hand skeletal Class II pattern is characterised by a smaller mandible with an increased overjet. The preferred option is to reduce the overjet by closing anterior spaces placing the permanent canines in the position of the lateral incisors. Techniques of cosmetic dentistry with veneers and acid etch technology can be applied to reshape the canines as lateral incisors to restore the anatomy of the substituted teeth to provide a balanced smile. Traumatic loss of a maxillary incisor can be treated orthodontically within the same guidelines as those for congenital absence of teeth

SUPERNUMERARY TEETH

Supernumerary teeth occur in up to 3% of the general population with a male female ratio of 2:1 and are more common in mongoloid races (Mason and Rule, 1995).

Location

Supernumerary teeth may be found in any dental area, but their most frequent sites are the third molar region and the maxillary midline. Supernumerary teeth are most often unerupted. Since the supernumerary teeth develop late, they are not often found in the primary dentition and when they do develop with the primary teeth they usually erupt. Supernumerary teeth in the region of the lateral incisors, either in the primary or permanent dentition, usually erupt into the arch.

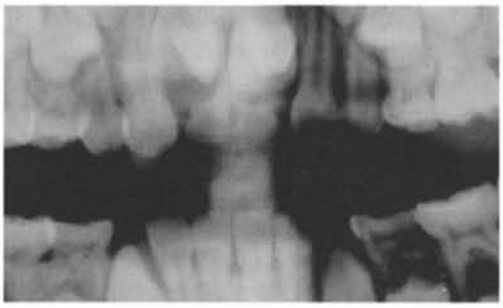


Fig. 8. A - Radiograph showing supernumerary teeth in the maxillary midline (mesiodens). Note delayed eruption of the permanent central incisors.

Fig. 8. B - Vertex occlusal radiograph showing supernumerary teeth in the palate.

Appearance.

Supernumerary teeth in the midline are usually smaller than normal teeth and peg-shaped with thin short roots. Those in the region of the maxillary lateral incisors often resemble normal incisor teeth and frequently approximate the size of the lateral incisors. (*Figs 8A & B*) Supernumerary teeth that develop in premolar regions are sometimes molariform, small and amorphous, they may be shaped like normal premolar teeth. (*Fig 9*)

Clinical Signs

The atypical size and anomalous form of the supernumerary tooth help to identify it. The problem in detection arises when the extra tooth closely resembles, both in size and shape, the primary or permanent tooth adjacent to it when it erupts in a normal position and does not crowd the adjacent teeth. Unless one has adopted the routine of counting each tooth, the supernumerary may be overlooked. Supernumerary teeth that erupt in the primary dentition, especially in the maxillary lateral incisor area, may not produce a space problem and can easily go unrecognised. Supernumerary teeth begin their calcification later than normal, because of this, they may be undetectable radiographically until age 11 or 12.

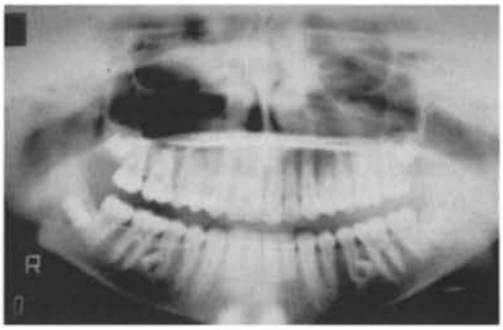


Fig. 9. Orthopantomagram (OPG) showing late development of supernumerary mandibular second premolars.

Supplemental Teeth

Supernumerary teeth which closely resemble the normal tooth alongside which they erupt are *supplemental teeth*. Their development apparently is the result of an equal splitting of the tooth germ which produces two teeth rather than one. Supplemental teeth are found most frequently in the maxillary and mandibular lateral incisor areas. They may be found in the primary as well as the permanent dentition. When one finds a supplemental primary tooth, the presence of succedaneous supplemental tooth in the same area in the dentition may be expected and should be looked for radiographically.

Effects

If the supernumerary tooth is unerupted it may delay or completely prevent the eruption of an adjacent tooth. The failure of a permanent tooth to erupt, if unattended, can cause malocclusion as adjacent teeth shift into the area that should be occupied by the permanent tooth which is late or has failed to erupt. Moreover, the supernumerary tooth can be a cause of ectopic eruption of teeth, which produces malocclusion (Nik-Hussein, 1990).

Unerupted or erupted supernumerary teeth can displace permanent teeth, cause them to rotate, produce diastema, deflect them mesiodistally or labiolingually and produce axial malposition. When unerupted they may also be factors in the development of dentigerous cysts, and in the resorption of roots of adjoining teeth. Therefore, even though supernumerary teeth may not produce malocclusion, they should be removed as soon as possible after detection to avoid future problems.

A supernumerary deciduous incisor may be retained if there is sufficient room for it. The tooth should be extracted when the permanent lateral incisor is ready to erupt. If there is an extra permanent lateral incisor, it may be removed at the same time. Identification of a supernumerary tooth that is similar in form and size to the tooth alongside which it erupts, can be made by looking at the comparable tooth on the opposite side of the dental arch and removing the one which less closely resembles in size and shape the normal lateral incisor. Usually, the more distal of the two teeth is the supernumerary tooth.

TIMED EXTRACTIONS

The total amount of inadequacy of arch length is the key to planning of timed extractions. For this to be beneficial a cephalometric analysis should show the child to be growing within a normal pattern and that all the permanent teeth are present radiographically and in normal order of eruption.

An arch length of less than 4mm in the mandible, can result in the loss of a deciduous canine as the lateral incisor erupts and midline shift to this side. The other deciduous canine should be removed and a lingual arch placed to support the incisors as the midlines correct themselves. As the permanent canines erupt, it may be necessary to reduce the mesial of the deciduous first molars and then as the first premolars erupt, reduce the mesial of the second deciduous molar.

Fig. 10. A - OPG showing impacted third molars.

Fig. 10. B - Same patient as 10A with late development of fourth molars.

Ectopic eruption of first permanent molars may resorb the distal margins of the second deciduous molars and is more common in the maxilla. This can be an indication of an inadequate arch length and a radiographic survey is required to confirm the presence of premolar teeth.

Where there is impaction of the permanent molar against the distal of the second deciduous molar, discing of the deciduous molar will allow the spontaneous eruption of the permanent molar. Where the resorbtion of the deciduous molar is advanced the loss of this tooth is indicated and space regaining mechanics considered once the permanent molar has erupted *(Figs 11, 12)* using an ACCO appliance as described earlier.

Where there is an arch deficiency of more than 4mm in each quadrant, serial extraction ending in the removal of four premolars may be considered. Here the purpose is to encourage the early eruption of the first premolars ahead of the permanent canines.

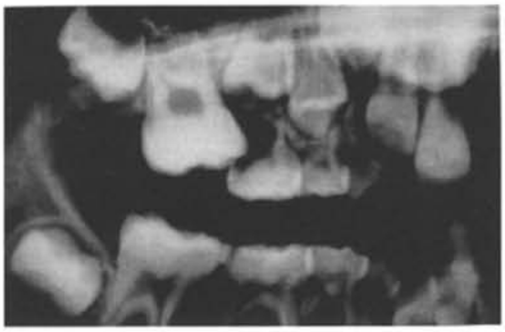


Fig. 11. Ectopic eruption of a maxillary first permanent molar resorbing the deciduous second molar and impacting the second premolar.

Fig. 12. Same case as figure 11 following the removal of the deciduous second molar and regaining space with an ACCO appliance.

Firstly the deciduous canines are removed to allow spontaneous alignment of the incisors. The deciduous first molars are then removed to allow the eruption of the first premolars. Once these are erupted, they are removed and a space maintainer issued to allow the permanent canines to erupt. Further orthodontic treatment is usually required to achieve correct root angulation and incisor torque. Thus serial extraction is a *planned procedure* which demands a minimum of *five years* supervision by the dentist of the developing occlusion. Without such a commitment, the objectives will not be achieved and the patient may well be left worse off than before.

Indications

The following points are essential when considering a serial extraction programmme:

1. Class I molar relationship.
2. Class I skeletal base.
3. Minimal overbite, overjet or open bite.
4. Radiographic and or clinical evidence of all permanent teeth.
5. Crowding of at least 4mm in each quadrant.

Contraindications to Serial Extraction

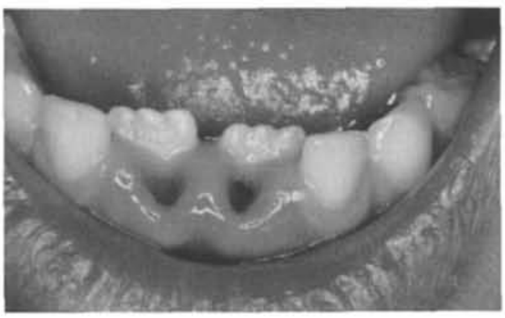
Serial extraction should not be performed in the following circumstances:

1. Class I malocclusions where the lack of space is slight and the teeth show only slight crowding.
2. When there are permanent teeth congenitally absent from the dental arch.
3. When there is a deep overbite or an open bite.
4. Where there is a skeletal discrepancy in the dental arches.

EXTRACTION OF OVERRETAINED PRIMARY TEETH

The earlier one can recognise and remove overretained primary teeth that may be causing ectopic eruption of a succedaneous tooth, the better the chances that a permanent tooth will erupt in a satisfactory position. The spontaneous and natural improvement that one may expect the permanent tooth to make following removal of the overretained primary tooth is illustrated *(Fig 13 A,B and C)*.

A



B

C

Fig. 13. A - Early mixed dentition showing eruption of the permanent mandibular central incisors lingual to the deciduous incisors.

B - Extraction of the mandibular deciduous incisors.

C - Natural alignment of the permanent central incisors due to tongue pressure one month following the removal of the deciduous incisors.

Ankylosis

Ankylosis is defined as a fusion of cementum of dentine to alveola bone (Biederman, 1962) and is a similar process to osseo-integration. The ankylosed primary molar may not be recognised in the very early stage. However, its condition can readily be diagnosed a short time later because the vertical level of the occlusal surface of the ankylosed tooth becomes noticeably shorter than the level of adjacent teeth, and as time progresses, this difference in vertical levels becomes more extreme. The ankylosed tooth can be readily identified by means of percussion producing a dull solid sound *(Fig 14A)*

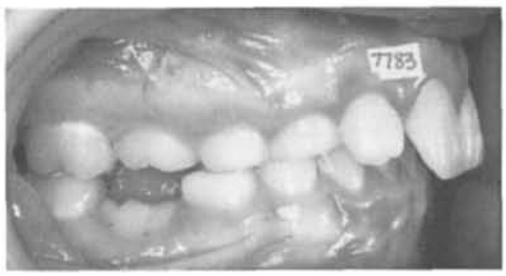


Fig. 14. A - "Submerged" second deciduous molar.

B - Radiograph showing "submerged" deciduous second molar and delayed eruption of the second premolar.

Because ankylosed teeth seem to be submerging, they have been called "submerged" teeth, but the term cannot be applied accurately to ankylosed teeth. It is more appropriate to call them "engulfed" teeth. The continued vertical eruption of the uninvolved adjacent teeth and the vertical growth of the alveolar process and periodontium creates the illusion that the ankylosed tooth is submerging. The primary ankylosed molar may be totally engulfed by the continuing vertical growth of the jaw (Sullivan, 1976).

The presence of ankylosed deciduous molars may interfere with the eruption and normal development of the premolars and delay the exfoliation of the deciduous tooth. (*Fig 14B*) Other complications are:

- ectopic eruption of premolars
- impaction of premolars
- loss of arch length
- mesial tipping of adjacent teeth over the ankylosed tooth
- super eruption of opposing teeth (Burch *et al.*, 1994).

Treatment

Ankylosed deciduous molars may be retained as long as they are maintaining arch length (ie preventing mesial shifting of the first permanent molars) or as long as they do not prevent the eruption of the succedaneous teeth. The value of ankylosed teeth as masticatory units of the dentition is lost early, once the continuing vertical eruption of the adjacent teeth takes the ankylosed tooth out of occlusion. However, they may serve for many additional months to maintain arch length integrity before they are no longer capable of preventing mesial tipping of the first permanent molars. The restoration of these teeth with stainless steel crowns to restore the occlusion is also a useful interim treatment. The deciduous molar should be extracted if the tooth becomes infra ocluded or mesial tipping of the first permanent molar is occuring (Messer and Cline, 1980).

When the deciduous molar is ankylosed and the premolar is congenitally absent, treatment is decided based on the presence of any malocclusion. If there is crowding and extractions are indicated as part of the orthodontic treatment, removal of the ankylosed tooth may be considered. Indeed, in borderline cases of extraction or non extraction, it is often preferable to extract the ankylosed tooth and orthodontically close the space so as to avoid future prosthetic replacement once the ankylosed tooth resorbs or is lost.

THE EXTRA ORAL APPLIANCE

(see Chapter 12)

Extra Oral Appliance Force

Malocclusions characterised by forward displacement of the dental arches can be treated with extraoral force using from occipital or cervical anchorage. The appliance should be worn 12 to 14 hours daily during the afternoon, evening and at night. The extraoral appliance must feel comfortable to the patient, and the force applied should be in the direction in which the teeth are to be moved. When gentle force is exerted by the appliance the teeth anterior to the molars that carry the appliance will also move distally.

The most favourable changes produced in treatment with extraoral appliances occur in young patients. The extraoral appliance is useful in some cases as a sole method of treating malocclusion and to reinforce anchorage when intraoral appliances are used. Extra oral appliances are also indicated for space regaining in the maxillary arch where bodily retraction of permanent molars is required.

Asymmetrical Extraoral Appliances

Force exerted by the extaoral appliance depends on:

- The point where the force is applied.
- The magnitude of the force.
- The direction in which the force is exerted.

When the direction of force from the cervical appliance is asymmetrical because of the difference in length of the facebow arms with respect to the midsagittal line of the face, then the anteroposterior components of force on the right and left molars are unequal. The molar nearest the longer arm of the facebow will receive the greater force.

Lateral forces of small magnitude are always developed by an eccentric design of the extraoral appliance. These forces can be controlled or manipulated to obtain lateral movement on one side or the other by springing the labial arch inward or outward. Biologic and morphologic variables in the dental arch can cause variation of unilateral or bilateral forces. Molar extrusion should be avoided especially in retrognathic mandibles, since the retrognathism is increased. The arms of the face bow should not impinge on the cheeks.

Facebow Angulation and Direction of Tooth Movement

When the arms of the bow of the headgear appliance are below the occlusal line there is distal tipping of the crowns of the molars. By raising the arms so that they are parallel with the line of occlusion, crown tipping is lessened. In this manner the axial position of molar teeth can be corrected.

Distal movement of the teeth anterior to the molars usually follows the molars. The interdental fibres of the periodontal ligament help the distal movement of the buccal series of teeth to move distally as a unit. When space develops mesial to the molar teeth as distal force is applied, it becomes necessary to move the premolars distally in turn and then to apply force on the incisors to move them distally. Spacing mesial to the molar teeth may be due also to excessive force.

Bite opening caused by elongation of molar teeth when using an extraoral force depends on the degree and direction of force applied, the nature of the alveolar bone, and muscle activity.

When active, vigorous muscular activity is exerted in chewing there is a tendency for the elongated molars to return to their original occlusal height.

When a biteplane that keeps the jaws apart is used in conjunction with an extraoral appliance, the possibility of elongating the molars is increased. This is not of value in correcting deep overbite, since the vertical height of the molars cannot be arbitrarily permanently increased. The overbite usually is caused by overeruption of the incisor teeth.

As the bite is opened there is a tendency for the mandible to assume a more retrognathic rotation in relation to the maxilla. This appears on the cephalometric tracing as a downward and rearward positioning of the mandible.

Shifting of permanent molars caused by premature loss of deciduous molars with encroachment on the premolar eruption space, can be prevented with the extraoral appliance. When dental arch-basal arch discrepancy is slight, it is possible by means of extraoral force to move the buccal segments distally and frequently to avoid extraction, especially if treatment is initiated in the early mixed dentition.

When using force from occipital anchorage, it is necessary to guard against impaction of third and possibly second molars, if the first molars are tipped too far distally. Additional appliances are usually needed to complete tooth positioning and rotations. The patient, preferably, or the parent in younger children, is taught how to place the extraoral appliance into position.

Construction of Extraoral Anchorage

Molar bands are cemented onto the first permanent molars. Solder tubes with 0.040 or 0.045 inch inside diameter, and attach rectangular tubes to hold an 0.020 inch archwire to be attached to the bracket bands on the teeth, as far gingivally and mesial as possible, for distal tooth movement. The labial archwire should lie opposite the gingival level of the incisor teeth. The molar tubes can be adjusted to permit root or crown tipping of the molars when desired.

The labial archwire is constructed of 0.040 inch or 0.045 inch stainless steel wire. Soldered or welded fixed stops are attached to the archwire to rest against the mesial ends of the molar tubes, while the arch rests labially 0.25 inch away from the incisor teeth. A 0.040 inch labial spur to receive the traction bar or face bow is soldered to the labial archwire at the median line. The face bow or traction bar itself also may be soldered to the archwire itself. Stops are soldered on the 0.045 inch labial archwire so that its anterior part is 4 to 5mm away from the incisors. The labial arch may be allowed to rest against the incisors if it is desired to move the incisors lingually, in which case the stops are placed on the archwire away from the anterior limits of the molar tubes so that the archwire can slide into the tubes as the incisor teeth are brought lingually. When the incisor axial relation is corrected the stops are replaced on the archwire to rest against the molar tubes to move the molar teeth distally. Another method of moving incisor teeth lingually is to attach hooks on the archwire of the extraoral appliance distal to the canines and to attach 3/8 inch rubber dam elastics that would exert pressure on the incisors.

The mesiobuccal cusps of the maxillary first molars can be rotated buccally by bending the ends of the labial arch buccally in front of the molar tubes. The traction bar or face bow on 0.070 inch round wire is constructed with hooked ends to hold the cervical gear. The cervical gear is made of 1.5 inch wide belting material. *(See Chapter 12)*

ACTIVE REMOVABLE APPLIANCES

When planning correction of a malocclusion it is necessary to determine the tooth movements required to achieve this. Treatment with removable appliances relies on the tipping of tooth crowns and guided eruption of teeth. Tipping forces produce a rotation of a tooth with the axis towards the apical third of the root. Thus succesful correction with removable appliances is by uprighting a tooth to a correct axial inclination.

Class II malocclusions

Class II malocclusons are characterised the mesial position of the maxillary first permanent molars relative to the mandbular first permanent molars. This is further reflected in the posterior positioning of the mandible and its dentition relative to the maxilla. Muscle function and lip relationship influence the axial inclinations of the incisor teeth . The distance between the the incisal edges of the upper and lower incisors in a horizontal direction is defined as the *overjet.* *(fig 16)* A lower lip trap will retrocline the lower incisors and procline the upper incisors, producing an increase in overjet which is dental rather than skeletal (Lew, 1991).

Large overjets combined with a lower lip trap expose the maxillary incisors to a greater risk of trauma and demand early correction. Where the overjet is of dental origin, a Hawley appliance may be used to retract the upper incisors by means of a labial arch wire so that the lower lip may rest comfortably labial to the upper incisors.*(Fig 15A & B)* Where there is a severe discrepancy in size between the maxilla and mandible, a functional orthopaedic appliance is indicated to correct the maxillo-mandibular relationship prior to the correction of individual tooth positions *(See Chapters 13 & 14)*. (Functional Appliances, Twin Block).

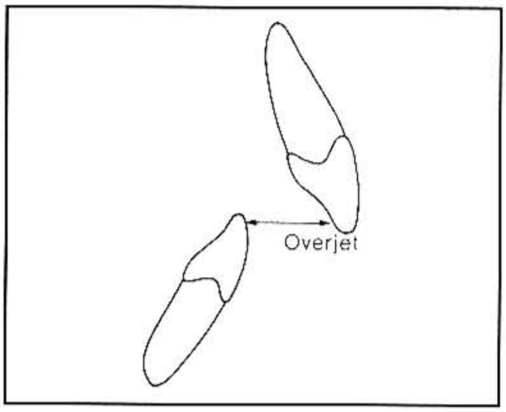


Fig. 15. A - Overjet is defined as horizontal overlap of the incisors.

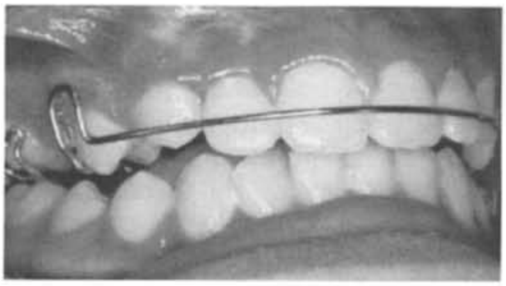


Fig. 15. B - Hawley retainer with anterior bite platform to allow the continued eruption of the mandibular molars.

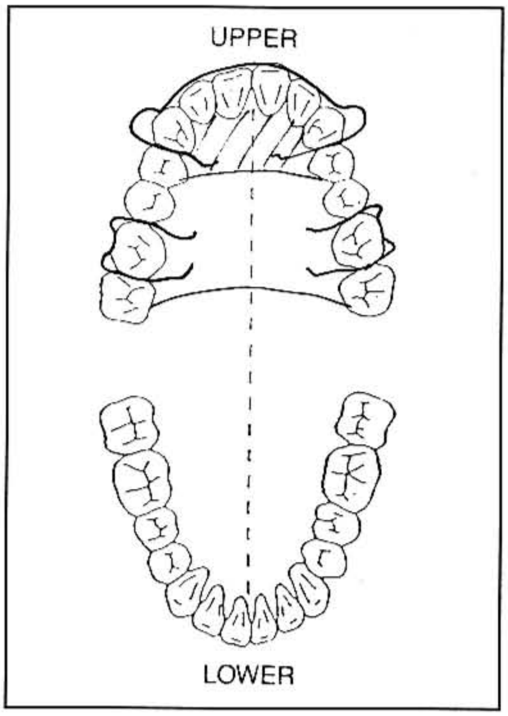


Fig. 15. C - Hawley Appliance - Laboratory design
- Adams clasps, teeth 16 & 26 0.7mm wire
- Labial arch, 13 to 23 0.8mm wire
- Full palatal cover
- Anterior bite platform.

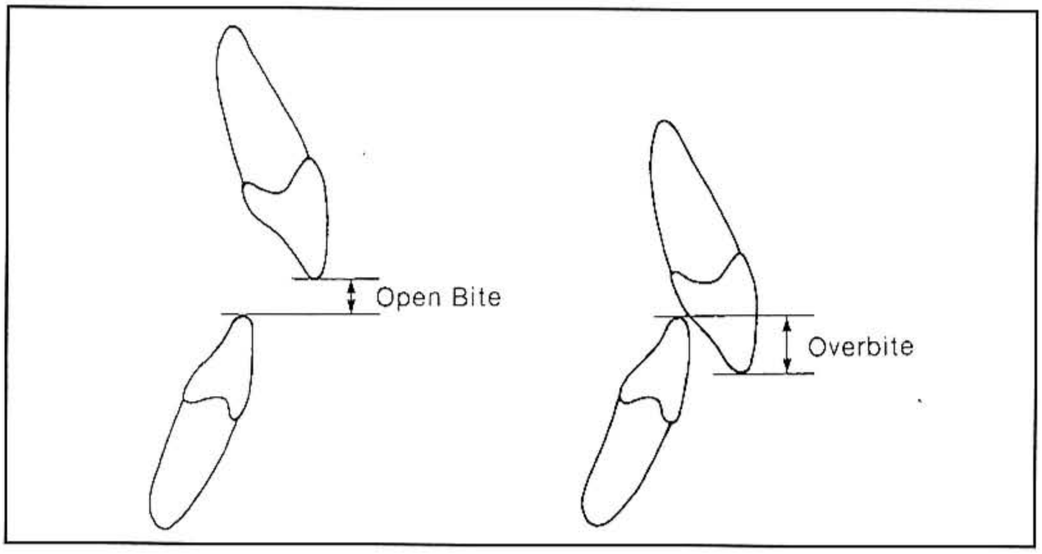


Fig. 15. D - Overbite is defined as vertical overlap of the incisors. Normally, the lower incisal edges contact the lingual surface of the upper incisors at or above the cingulum, ie. normally there is 1to 2 mm overbite. In open bite, there is no vertical overlap, and the vertical separation is measured.

An increase in the vertical overlap of anterior teeth is defined as *overbite*. Correction of this at an early age is recommended to permit the normal development of the dentition. Either a Hawley appliance with an anterior bite platform or Sved appliance *(Figs. 16A & B)* may be issued. These appliances limit the amount of overbite by resricting the vertical eruption of the lower incisors. The open posterior interocclusal space permits the full eruption of the premolars and molars into occlusion levelling the curve of Spee *(Figs. 17A & B)*.

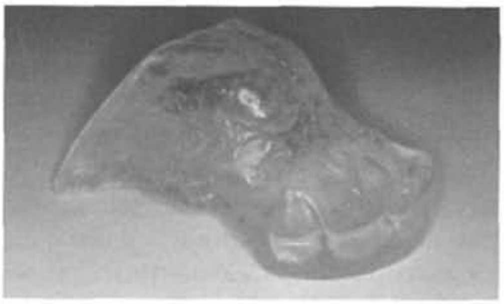


Fig. 16. A & B - Sved plate. Does not have any clasps. Retention is via capping on the incisors and allows continued eruption of both maxillary and mandibular posterior segments.

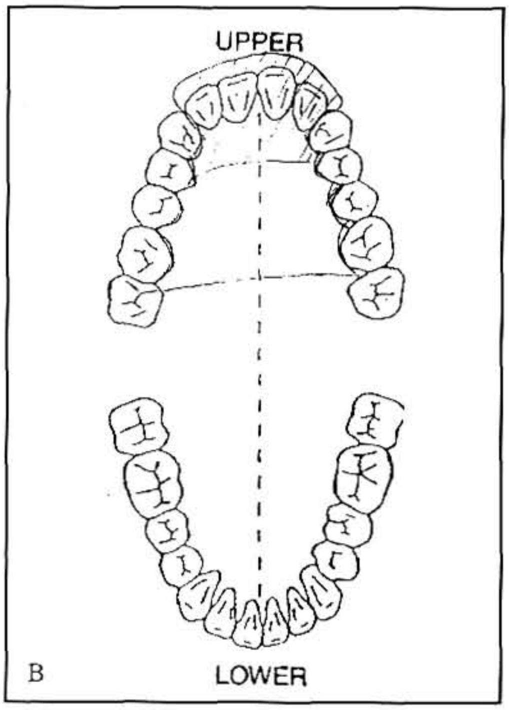


Fig. 17. A - Sved plate showing anterior bite platform to open the bite.

B - Laboratory design for a sved plate.
- palatal cover
- acrylic capping incisors 3mm
- anterior bite platform with inclined plane to hold mandible forward
- "no clasps"

CLASS III MALOCCLUSIONS

Anterior crossbites

Anterior cross bites are one of the most common malocclusions presenting in the mixed dentition. An incisor may erupt ectopically either palatally in the maxilla or labially in the mandible to a crossbite relationship in centric occlusion. This may occur in a child with a balanced skeletal relationship. Early treatment is only necessary if there is a deviation on opening and or closing or if there is a traumatic occlusion or periodontal concerns. Otherwise treatment can be delayed until the full permanent

dentition erupts. An anterior crossbite may be associated with a skeletal Class III discrepancy such that although the incisors are positioned correctly within the alveola ridges, they are in negative overjet on closing into centric occlusion with no deviation of mandibular closure.

A pseudo Class III pattern occurs where there is an habitual mandibular closure pattern where the mandible goes into protrusive and thus crossbite of incisors avoiding traumatic occlusion. This anterior shift of the mandible can affect the growth of both the maxilla and the mandible with undesirable muscle adaptation.

Treatment

Inclined Plane

Where there is a functional shift of the mandible into an anterior crossbite, an acrylic inclined plane can be fitted to the lower incisors to restrict the forward posturing and place pressure on the palatal of the maxillary incisors to push them labially. Treatment is usually complete within a month, this appliance works best where there is a slight increase in overbite which helps to retain the incisors in positive overjet once the appliance is removed.

Tongue Blade Technique

If the patient is seen when the permanent incisors are still erupting and there is only one incisor in cross bite without an excessive overbite, a tongue blade or paddle pop stick may be used to correct this (Richardson, 1982). A demonstration of the tongue depressor blade technique is given to both the patient and the parents. The patient watches the procedure while holding a large hand mirror. A tongue depressor blade is placed lingual to the upper incisor tooth in crossbite, and the patient is instructed to close the lower incisor teeth firmly against the blade while it is held in position. The operator then takes the patient's hand, places it on the tongue depressor blade, and guides the blade downward and backward against the lower lip and the chin, making sure that the firm biting pressure the child is asked to exert on the tongue depressor blade is not lessened.

Holding the tongue depressor blade in this position and biting firmly against it, the patient is instructed to count out loud to 50 apples as follows: One apple, two apples, three apples etc. If apples is added to the counting, it spreads the timing taking the patient approximately one minute to reach 50. The patient is then instructed to remove the tongue blade and rest a while before repeating the exercise.

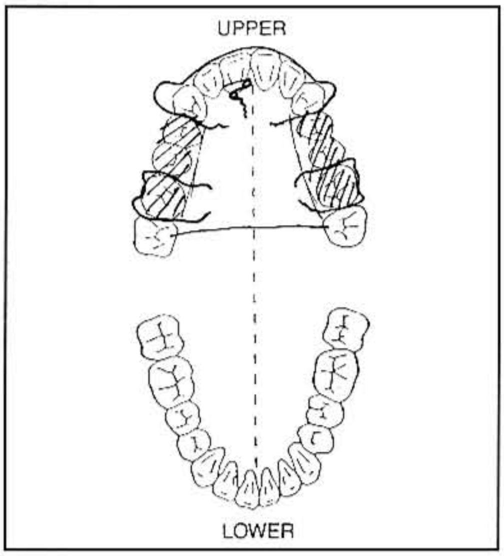
Six sessions are required daily with an interval of at least half an hour. Both the patient and the parents are advised that if the tongue depressor blade is used in the proper fashion the teeth will become quite tender after the first day of use, but that in spite of this it needs to be carried out daily. If the exercise is discontinued for a day or two until the teeth once more become comfortable, all prior progress will be lost and the patient will be back where he started. Correction of a simple incisor crossbite is often complete within a few days with the patient checked every week.

Removable Appliances

A modified Hawley appliance can be used in the maxilla to correct one or two teeth in crossbite (Jacobs,1989). It is helpful to cover the occlusal surfaces of both the deciduous and permanent molars to open the bite and allow free labial movement of the teeth in crossbite. Adams clasps are placed on the first permanent molars with a labial arch wire. If the deciduous molars are present, ball ended clasps can be fabricated to engage the interproximal areas of these teeth.*(Fig 18)*

A

B



C

Fig. 18. A - Permanent central incisor in crossbite in the mixed dentition.

B - Removable appliance in place with occlusal cover to open the bite and allow for proclination of the incisor.

C - Anterior cross bite - *Modified Hawley Appliance*
- Adams clasps, teeth 16 & 26 0.7mm wire
- Labial arch, 13 to 23 0.8mm wire
- Z spring palatal to the tooth in cross bite 0.7mm wire
- Occlusal cover over posterior teeth to open the bite and allow correction of the cross bite.

Where a single tooth is in crossbite, a Z spring placed palatally to the malposed tooth can be used or if both central incisors are in crossbite two springs can be used to provide sweep arms on the palatal surface. The appliance should be fitted and check for comfort with springs passive. The patient is then seen after four weeks to activate the springs and check the retention of the appliance.

Active removable appliances should be worn 24 hours per day except for eating, cleaning of teeth and playing sport. Appliances should be cleaned with a tooth brush and soapy water. Appointments are made each four weeks and the appliance activated. Enough pressure to *tickle the periodontium* is all that is required to allow tooth movement. The patient will indicate to you that the active component is snug and there is pressure on the tooth to be moved. If following an adjustment of a spring, the gingiva is blanched, this is a sure sign that the appliance is over activated.

As with all removable appliances success of treatment is reliant on cooperation and compliance. If these qualities can be encouraged in the patient and the patient takes responsibility for the wearing of the appliance, treatment will progress satisfactorily.

Following correction of the cross bite, the occlusal cover of the posterior teeth is trimmed away to allow the bite to close. The same appliance can be used as a retainer to stabilise the occlusion for at least three months.

Fixed Appliances

Fixed appliances can be used when two or more incisors are in crossbite. Brackets are direct bonded to the incisors with bands cemented to the first permanent molars. A labial arch of 0.016 round wire is used with vertical loop stops mesial to the molar tubes. These loops are expanded to procline the

incisors and the round wire permits labial tipping of the incisors to correct the crossbites.

Where the incisor crossbite is a combination of palatal inclination of maxillary incisors and labial inclination of the lower incisors, fixed appliances can be used in both upper and lower arches on the incisors and first permanent molars. As well as vertical stops in the maxillary arch wire to procline the maxillary incisors, 5/16 2oz Class III elastics (from maxillary molars to mandibular canines) can be utilised. The elastics need to be worn 24 hours per day except for tooth brushing and replaced every three to four days. This appliance will provide rapid correction of the crossbite within six months. Retention with a upper removable appliance should follow for at least six months. *(Figs 19A, B & C).*

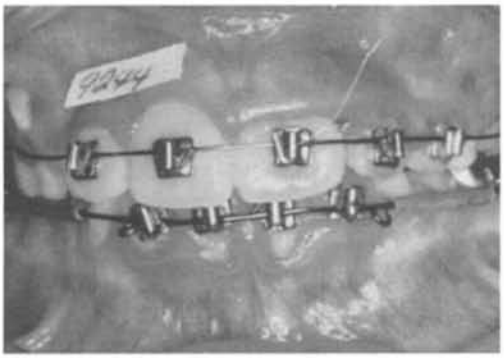


Fig. 19. A - Anterior cross bite.

B - Upper and lower fixed appliances central incisor corrected within six months.

C - At bands off.

Posterior Crossbites

A posterior crossbite is a transverse discrepancy in arch relationship (Ninou and Stephens, 1994) There are three types of posterior crossbites, dental, functional and skeletal. A dental crossbite involves only tilting of teeth, a functional crossbite involves a mandibular shift with muscle adaptations as a result of the tooth interferences. A skeletal crossbite is related to skeletal discrepancies between maxilla and mandible. A bilateral crossbite occurs where there is a large skeletal discrepancy. Insufficient arch length or prolonged retention of deciduous teeth can deflect teeth during eruption and produce a crossbite. Prolonged thumb and finger sucking has also been implicated in the narrowing of the maxillary arch with molar crossbites. This is also a regular presentation in cerebral palsy.

Functional posterior crossbites should be treated as early as possible to allow normal growth and development of the dental arches and temporomandibular joints (TMJ's). When planning treatment it is important to determine whether the crossbite is unilateral or bilateral. The majority of crossbites are

bilateral but often present as unilateral when the teeth are in full intercuspal position. In these cases the dental midlines will not be coincident on closing and there is a deviation of the mandible towards one side at the end of closing. When the teeth are closed with the dental midlines coincident, the posterior segments will be in an edge-to-edge, bucco-lingual position, reflecting the overall constriction of the maxillary dental arch and bilateral maxillary expansion is indicated.

When only a single molar is in crossbite, this can be corrected with a bonded attachment, button or hook, to the palatal of the maxillary and buccal of the lower molar. An elastic ($^1/_4$ inch $3^1/_2$oz (100gm)), is stretched between these and worn 24 hours per day and changed every time they break (which is often). Such crossbites will normally correct within 3-4 months with continuous wearing of the elastics. The major change will be reflected in the position of the maxillary molar due to the cancellous nature of the maxillary alveola bone, as against the denser bone around the mandibular molar.

A true unilateral posterior crossbite of two teeth can be corrected with a removable appliance with a jackscrew offset in the palate.*(Fig 20A)* This appliance relies on good retention by way of the Adams cribs as the screw is activated $^1/_4$ turn each week. Where the jackscrew is central over the midpalatal suture, such an appliance can also be used for bilateral expansion of dental arches *(Fig 20B)*. With both these appliances the correction is dental only with the major component of tooth movement being a tipping only. A more extensive unilateral crossbite without mandibular deviation, may reflect underlying pathology such as cleft palate or unilateral condylar hyperplasia.

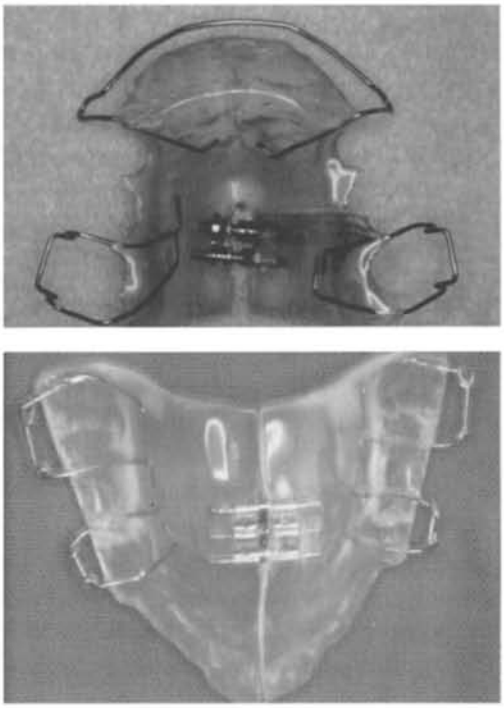


Fig. 20. A - Removal appliance with palatal screw to correct a maxillary molar cross bite.

B - Removable appliance with mud-palatal expansion.

Fixed appliances may be directed at dental correction or orthopaedic involving splitting of the midpalatal suture. A quad helix appliance soldered to molar bands cemented to the first permanent molar, provides predictable dental correction.*(Fig 21)*

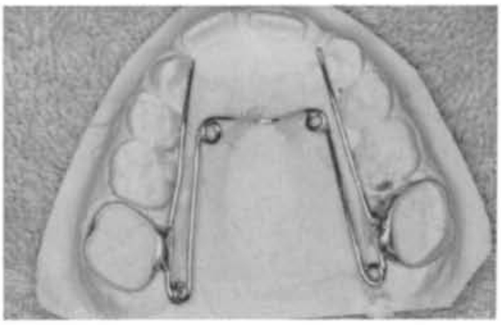
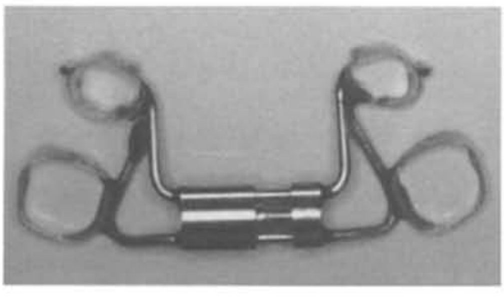


Fig. 21. A quad helix appliance cemented to the permanent maxillary molars.

This appliance requires little cooperation from the parents or patients apart from avoiding sticky foods. The appliance is fabricated on a working model and cemented passively. At least four weeks should be allowed for the patient to get used to it then the helix can be expanded in the mouth with Howe pliers or Jarabaks. From then the patient is seen each four weeks with the appliance removed expanded and recemented each alternate appointment. The expansion should continue until the molars are overcorrected, then retained with the same appliance for a further three months. The crossbite is usually corrected within 4-6 months followed by retention.

Rapid maxillary expansion involves the splitting of the midpalatal suture and produces an orthopaedic increase in maxillary width. The appliance uses a midpalatal screw soldered to bands on the first permanent molars, deciduous molars or premolars. In contrast to the removable appliance, the screw is activated a quarter turn twice each day and the patient should be monitored once a week. *(Fig 22A & B)* As the expansion proceeds, a diastema will show between the central incisors, reflecting the splitting of the midpalatal suture. This will close as the bone remodels and the parents an patients should be warned of this. As with a quad helix, the crossbite should be over corrected and retained in this position for at least three months with the same appliance.



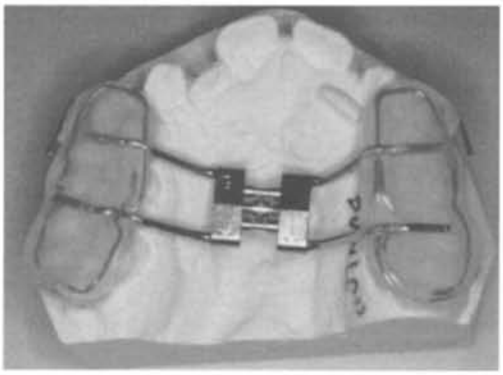


Fig. 22. A - Rapid maxillary expansion appliance. Bands are fitted to the first premolars and first permanent molars, a mid-palatal screw is turned 1/4 turn, twice per day.

B - Bonded maxillary expansion appliance.

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8
The Impacted Maxillary Canine

Stanley Jacobs

INTRODUCTION

Patients with impacted canines form a significant proportion of those requiring treatment in orthodontic and oral surgery departments. The canine has been described by Hunter (1981) as the cornerstone of the maxillary arch because of its long root and associated bony support. It is relatively resistant to caries and periodontal disease and plays an important role during mandibular lateral excursion. It has aesthetic value and is ideal for use as an abutment in fixed prosthetics.

INCIDENCE

The incidence of impacted maxillary canines is approximately 1-2 per cent per maxillary quadrant (Thilander and Jakobsson 1968, Brin *et al.*, 1986, Ericson and Kurol 1987b). The condition occurs bilaterally in 16-25 per cent of patients with impacted canines (Bass 1967, Rayne 1969, Wolf and Mattila 1979).

POSITION

The majority of impacted canines are palatal and in a mesio-angular position but canines may also be found:

- labially
- in the line of the arch:
  - i lying vertically between the teeth
  - ii lying horizontally across the arch
- in an abnormal position e.g. naso-antral wall.

Wolf and Mattila (1979) found in a series of 116 impacted maxillary canines 75 per cent were palatal, 9 per cent were labial to the roots of adjacent teeth while 16 per cent were located in the middle or almost in the middle of the alveolar ridge.

Fig. 1a. Palatal 13 rotated 180°.

Fig. 1b. Patient at deband. 13 rotation maintained.

Figure 1a shows a palatal canine which was rotated 180 degrees. Figure 1b, taken after band removal, shows 13 in the line of the arch. It had been decided not to eliminate the rotation.

NORMAL DEVELOPMENT

An understanding of normal development will help to detect abnormalities in the position of the erupting canine and understand the aetiology of impactions.

Hunter (1981) stated that the crown of the permanent canine begins calcification at 4 to 5 months and at 1 year is found lying high in the maxilla above the bifurcation of the first deciduous molar and below the floor of the orbit. From this position to the occlusal plane the path of eruption is tortuous and difficult. As the deciduous teeth erupt, the permanent incisor and canine crypts migrate rapidly forward in the maxilla. By the age of 3 years the permanent canine lies just above the apex of the deciduous canine, the crown being directed mesially and somewhat palatally. While growth of the face continues and carries the deciduous dentition downwards and forwards, the canine remains high in the maxilla, its root development only beginning at the age of 7 years. As the root begins to form the canine moves towards the occlusal plane the crown lying in close proximity to the root of the lateral incisor. It travels down the distal aspect of this root emerging into the mouth at the age of 11 to 12 years.

AETIOLOGY OF IMPACTION

One problem in reviewing the literature is that it is frequently assumed that labial impactions have the same aetiology as palatal impactions. This probably is not the case.

Possible factors

- It seems plausible that the long tortuous path followed by the canine during its eruption would predispose to impaction.
- Crowding has been suggested as an aetiologic factor (Kettle 1958). However, Dewel (1945) thought that palatally impacted canines occur most often in cases where there is usually almost enough space to accommodate them. Studies of patients with palatal canines show the percentage of uncrowded maxillary arches ranges from 36-85 per cent (Bass 1967, Jacoby 1983, Becker 1984, Zilberman *et al.*, 1990). In contrast, all 10 of Bass's (1967) treated labially impacted canine patients showed some maxillary arch crowding. Also, 5 out of 6 (83 per cent) of Jacoby's (1983) labially impacted canines had an arch length discrepancy.
- Anomalous lateral incisors are involved. Becker *et al.*, (1981) studied the morphology of lateral incisors adjacent to 88 palatally displaced canines. They classified the incisor as normal, small, peg-shaped or absent. Anomalous

Lateral Incisor Categories	Distribution in Sample (per cent)	Distribution in 75 Canine Impactions (per cent)	Probability of Canine Impaction (per cent)
Normal	92.9	57.3	1.0
Small	4.0	25.3	9.8
Peg	1.8	13.3	11.5
Absent	1.3	4.0	5.0

Table 1. Lateral incisor categories associated with palatal canines

adjacent lateral incisors were found in 47.7 per cent of the cases. Brin *et al.*, (1986) examined 2440 adolescents for maxillary lateral incisor anomalies and maxillary canine position. They found 75 palatally impacted canines. Table 1 shows:

i the distribution of the lateral incisor categories;

ii the distribution of the 75 palatal canines in the various categories; and

iii the probability of palatal canine impaction per category.

It can be seen from Table 1 that if a patient has a small or peg-shaped lateral incisor there is approximately a 1 in 10 chance that the canine will be palatally placed. If the lateral incisor is completely absent there is less likelihood of the canine being palatally placed - a 1 in 20 possibility. The overall incidence of palatally impacted canines was 1 in 65 quadrants (1.53 per cent).

Becker *et al.*, (1981) explained how the presence of anomalous lateral incisors encouraged palatal displacement of canines. There appear to be two processes in the palatal displacement of the maxillary canine. The first is a developmental one, related to absence of guidance by the lateral incisor, which opens a new course for a downward path on the palatal side. The second relates to a more advanced period, when the tooth is moving down into a narrower part of the alveolar process. If given the space or only the interference of deciduous tooth roots, it will tend to improve its position and frequently break through the mucosa on the labial side. It is the presence of permanent tooth roots at this late stage that can prevent the rectifying movement of the canine. This would account for the high incidence of peg-shaped and otherwise small lateral incisors that are found adjacent to palatally-displaced canines and the relative infrequency of congenital absence. They also noted that small teeth develop late.

Becker *et al.*, (1984) found that there was a definite link between lateral incisor crown and root size. Since roots of small and peg-shaped lateral incisors tend to be shorter than roots of lateral incisors with normal crowns, their reduced mesio-distal crown width may be merely a reflection of the short root. They regarded the short root as the more likely critical factor together with the lateness in development depriving the canine of needed guidance in the early stages of development.

Genetics plays a role.

i Familial tendency

Zilberman *et al.*, (1990) have shown that family members (parents and siblings) of patients with palatal canines are themselves likely to exhibit:

- palatally displaced canines;
- anomalous lateral incisors;
- absence of crowding;
- late developing dentitions.

ii Syndrome manifestation

Bjerklin *et al.*, (1992) investigated the associations between tooth and eruption disturbances in four groups of children selected primarily with only one diagnosed eruption or developmental disturbance in each group. The groups comprised children with either:

- ectopic eruption of maxillary canines; or
- infra-occlusion and ankylosis of primary molars; or
- ectopic eruption of maxillary permanent first molars; or
- aplasia of premolars.

These authors concluded that the four conditions were different manifestations of a hereditary syndrome. In particular, ectopic eruption of maxillary canines showed a significantly higher prevalence than expected in all the other three groups. They suggested that with closer follow-up of the maxillary canines during the eruption period in children with some of the other three disturbances, prophylaxis or early interceptive measures may be taken and complicated orthodontic treatment could be reduced or avoided.

Delayed resorption of the deciduous canine has been suggested as an aetiologic factor. A more likely explanation is that delay in eruption and abnormal position of a canine result in the tardy resorption of the deciduous predecessor (Thilander and Jakobsson 1968, Richardson and McKay 1982, Schmuth *et al.*, 1992).

EXAMINATION

The examination of a patient can be discussed under the headings of:

- History and assessment
- Inspection
- Palpation
- Special Tests.

In the case of an unerupted maxillary canine, the clinician should evaluate the patient, the position of the unerupted canine and the malocclusion (Hunter 1983a).

The patient

History and assessment

A dental, medical, social and familial history should be elicited. In addition, an assessment should be made of the patient's concern and desire for treatment.

The position of the unerupted canine

Inspection

One may see:

- the bulge of the unerupted tooth (Figure 2); and/or
- the position of adjacent teeth being influenced by the unerupted tooth.

The position of maxillary lateral incisors is influenced by impacted canines far more frequently than the position of the premolars is affected. This is because most impacted canines:

- are mesio-angular impactions; and
- have migrated mesially as well (Wolf and Mattila 1979).

The crown of a palatal canine may push the lateral incisor root labially and the crown of this incisor palatally (Figure 2), whilst a labially impacted canine can have the opposite effect pushing the lateral incisor's root palatally and its crown labially.

Fig. 2. The bulge of the unerupted 13 can be seen by comparing the palatal rugae of the right and left sides. The underlying 13 has pushed crown of 12 palatally and the root labially.

Palpation

Usually a properly erupting canine can be palpated when the patient is 10 years of age. Occasionally however, the bony canine eminence can be confused with the tooth and so the fact that a canine is impacted can be missed. The clinician should manipulate the deciduous canine to determine if it is mobile. If it is, this indicates that its root has undergone significant resorption. However, this mobility cannot be taken as conclusive evidence that the permanent canine is erupting in the desired direction (Ericson and Kurol 1987a).

Special tests

Radiographs are required to accurately localise impacted canines. From the radiographs should be determined:

- the position of the crown and the apex of the canine;
- the angulation of the canine; and
- the condition of the roots of the adjacent teeth to determine whether resorption is occurring.

Ericson and Kurol (1986) suggested the following indications for radiographic control of suspected maxillary canine eruption disturbances:

- asymmetry in palpation or a pronounced difference in eruption of canines between the left and the right side, i.e. one canine may be in an unfavourable position and the other is favourably placed;
- the canines cannot be palpated and occlusal development is advanced suggesting an abnormal path of eruption, i.e. possibly both canines are in poor positions;
- the lateral incisor is proclined and tipped distally as this position may indicate a buccal ectopic eruption. Distal tipping alone was not associated with any eruption disturbances.

According to these criteria, 8 per cent of children over 10 years may require a supplementary radiographic examination (although, as said above, the actual incidence of impacted canines is 1-2 per cent).

To summarise the situations where the clinician should suspect maxillary canine impaction may develop or has developed:

- before 10 years of age
  - i when maxillary lateral incisors are anomalous or absent (Becker *et al.*, 1981);
  - ii when family members have palatally displaced canines (Zilberman *et al.*, 1990);
  - iii when infra-occlusion and ankylosis of primary molars and/or ectopic eruption of maxillary permanent first molars and/or absence of premolars exists (Bjerklin *et al.*, 1992).

- after 10 years of age when any of the 3 indications for radiographic control given by Ericson and Kurol (1986) are present.

Accurate methods of localisation

The most widely recommended technique to localise impacted canines is to use the tube shift principle (parallax method, Clark's method (Clark 1910), buccal object rule). This technique utilises the phenomenon that the image of the farther away of two objects moves in the same direction as the X-ray tube has moved and the image of the closer object moves in the opposite direction to the shift of the tube (Figure 3).

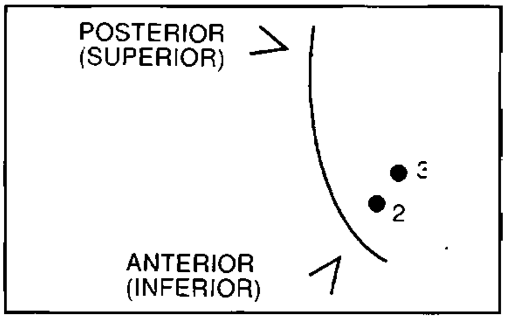


Fig. 3. Diagram illustrating horizontal (and vertical in brackets) tube shift. The canine when viewed from the anterior (inferior) position of the tube is obscured by the lateral incisor. However, when viewed from the more posterior (superior) position of the tube the canine is closer to the tube than the lateral incisor i.e. the palatal canine has moved in the same direction as the tube has shifted.

The acronym SLOB helps in remembering the tube shift principle since it is short for Same (direction of movement as the tube then the tooth is) Lingual Opposite (direction of movement to the tube then the tooth is) Buccal (Goaz and White 1987).

Usually periapical radiographs are used to illustrate the tube shift principle. A more favoured combination of radiographs is two occlusal radiographs - an anterior and lateral occlusal (Keur 1986). Occlusal films are preferred because:

- the tube can be moved much more between the two exposures (and the integral absorbed dose is comparable to that of periapicals). The more the tube is shifted the more the image of the impacted tooth will move in relation to the image of the reference tooth and the more certain is the diagnosis of its position;
- frequently part or all of the crown or the root of the impacted tooth is not captured on periapical films because the smaller periapical films are more difficult to take well (Jacobs 1986).

Another combination of films which can be used is an orthopantomogram (OPG) (which may have been taken already) and a single occlusal (Keur 1986). The tube shift is in the vertical plane because an OPG is taken at an effective angle of +7° to the occlusal plane, the occlusal at +60°.

The principle of tube shift in the vertical plane may be understood from Figure 3 if inferior is substituted for anterior and superior for posterior. A vertical tube shift is also illustrated in Figure 4.

A disadvantage of the tube shift method is that it does not provide accurate information regarding the distance between the impacted tooth and the reference tooth. However, an experienced operator can estimate this distance by relating the amount of tube shift and the amount of image shift.

The vertex occlusal radiograph has been recommended to determine the relationship of impacted canines to the midline of the dental arch (Ericson and Kurol 1987b).

There are disadvantages with this view:

- a long exposure is required with the ordinary dental apparatus and the patient may move and spoil the radiograph;
- the image is always rather indistinct owing to the superimposition of various structures in the area;

- the absorbed dose to various radio-sensitive organs is substantial for the brain, *the pituitary, salivary glands, thyroid* and the lenses of both eyes receive unnecessary exposure (Keur 1986); and
- it is particularly deceptive when the lateral incisor is lying obliquely.

Less accurate methods of localisation

Canine image on central incisor root.

Wolf and Mattila (1979) observed that the closer to the intermaxillary suture the position of the impacted canine the more frequent was a palatal location. All their 47 cases in which the canine crown was projected at the site of the root of the central incisor were located palatally. However, if on an OPG a canine is seen to be projected on to the root of the central incisor the operator should still take an occlusal to confirm that the canine is palatally placed (Jacobs 1988).

Image magnification

If two objects are of equal size, then the object closer to the focal spot of the tube and further from the film will produce a larger image on a film than an object further from the focal point and closer to the film. Wolf and Mattila (1979) concluded that determination of the labiopalatal location of impacted teeth based on a single OPG using the principle of image magnification is unreliable. Nevertheless, image magnification may be a helpful supplementary tool. At the very least, if the crown of an unerupted canine is relatively enlarged in comparison with its neighbours on an OPG the operator should take an occlusal radiograph to determine whether the canine is malpositioned.

The malocclusion

The availability and requirements of space should have been determined, together with the complexity of treatment necessary to align the remaining teeth. In addition, a full evaluation of the teeth and supporting structures should be carried out (Hunter 1983a).

TREATMENT METHODS

It is important to explain treatment alternatives fully, particularly the commitment required for and expected duration of orthodontic treatment.

Prevention/Interception

Ericson and Kurol (1988a) suggested that extraction of the deciduous canine is the treatment of choice to correct palatally ectopically erupting maxillary canines in individuals aged 10-13 years, provided that normal space conditions are present. In 36 of the 46 canines they investigated, the initially palatal eruption path changed to normal and the canines finished in a clinically correct position. All 36 canines which improved did so within 12 months and were in clinically good positions at 18 months. Ninety-one per cent of the canines which initially overlapped the adjacent lateral incisor root by less than half on the OPG normalized. Sixty-four per cent of the canines which initially overlapped the lateral incisor by more than half of the root normalized. The degree of palatal position relative to the dental arch at the start of treatment also influenced the result. More canines with a moderate palatal path of eruption normalized than canines in a true palatal position (90 per cent and 65 per cent respectively).

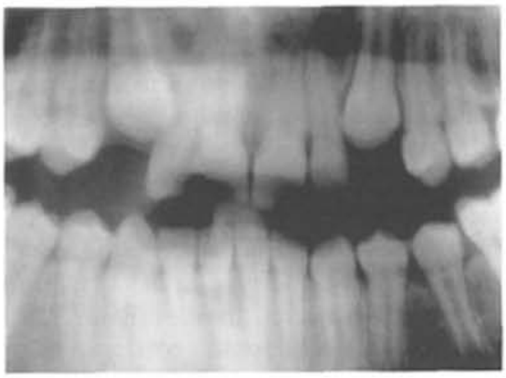
The patient in OPG 1 (Figure 4a) was aged 11 years 9 months. In OPG 2 (Figure 4b) taken 11 months later, the position of 13, 23 had not improved. A vertical tube shift between OPG 2 (Figure 4b) and the maxillary occlusal (Figure 4c) shows 13, 23 moved up towards the apex of 12, 22 on the maxillary occlusal (Figure 4c). Therefore it could be deduced that 13, 23 were palatal. The 53, 63

were extracted at the time OPG 2 (Figure 4b) was taken. Six months later 0.5 mm of 23 had erupted in the line of the arch OPG 3 (Figure 4d). The position of the unerupted 13 had improved also. A further 6 months later, 1 mm of 13 and 3 mm of crown of 23 were visible in the mouth (Figure 4e).

A

B

C



D

E

Fig. 4a. OPG 1. Note the position of 13, 23 in relation to 12, 22.

Fig. 4b. OPG 2 taken 11 months after Figure 4a. Position of 13, 23 has not improved. The 53, 63 were extracted at this time.

Fig. 4c. Maxillary occlusal. The images of 13, 23 are closer to the apices of 12, 22 than in Figure 4b taken at the same time.

Fig. 4d. OPG 3 taken 6 months after Figure 4b. 23 is erupting in line of arch. Position of 13 has improved also.

Fig. 4e. Six months after Figure 4d. 1 mm of crown of 13 visible, 23 has erupted further.

Leave in situ (i.e. no treatment)

A patient may not wish to consider treatment if he/she judges that the existing dental appearance is satisfactory. This will often be the case where the deciduous canine is retained, has not suffered extensive attrition or carious attack and where there are no other cosmetically significant features of a malocclusion. Figure 5 shows the appearance of a retained deciduous maxillary canine in a 40 year old female.

Fig. 5. Retained 63 in a 40 year old female. The appearance of 63 was acceptable to the patient.

Leaving the unerupted canine in situ, however, may predispose to problems such as incisor root resorption or cystic change of the follicle. Resorption, in particular, may be rapid although it will usually cease when the canine is removed; nevertheless, the risk of this occurrence should be taken into account if it has been decided to leave the canine in place and radiographic monitoring at intervals may be advisable (Ferguson 1990). Resorption is further discussed, under Complications. Richardson and McKay (1983) warn against leaving unerupted canines in situ.

Occasionally the tooth may be so misplaced that its removal would cause extensive damage to adjacent structures. In these instances the tooth should be kept under periodic review.

Removal

Surgical removal of the canine will eliminate the risk of incisor root resorption occurring, and such treatment will again be most appropriate when dental aesthetics are already satisfactory or the patient is unwilling or unable to undergo treatment to align the canine. The prognosis for the long-term survival of the deciduous canine should be assessed as far as possible, and the patient appraised of the options for further treatment if it is eventually lost. In this case orthodontic space closure can sometimes be undertaken, but usually this is not a realistic option if the patient has already rejected the idea of appliance therapy. Creation of an aesthetically satisfactory contact between the lateral incisor and first premolar is not always easy and generally requires the use of fixed appliances. The prognosis for this treatment will be that much poorer if there is already a pre-existing mesiopalatal rotation of the premolar. If the space cannot be closed, it may have to be accepted or eliminated by restorative procedures.

Where marked crowding is present, space closure may occur spontaneously if the deciduous canine is lost early; however, even under these circumstances, a decision to remove the buried permanent canine should not be taken without considering the occlusion as a whole. Quite frequently a significant centre-line shift will be apparent, and if this is to be corrected as part of the overall orthodontic treatment plan space may tend to open between the lateral incisor and premolar in which case it may well be more appropriate to accommodate the canine in the arch (Ferguson 1990). If the impacted canine is removed the palatal cusp and the mesial marginal ridge of the first premolar will often require grinding to eliminate interference with opposing teeth.

Exposure and alignment give the best results. At the end the patient has a precisely positioned vital tooth with a non-traumatised root and periodontal membrane.

Surgical methods

Exposure

Hunter (1983b) has described the methods of surgical exposure. Surgical exposure of an unerupted canine is aimed at:

- removing hard and soft tissues impeding the path of eruption;
- uncovering an area of enamel onto which a suitable attachment may subsequently be placed to start tooth movement.

Following the exposure a surgical pack is placed for one to three weeks, to prevent re-epithelialisation over the exposed area of enamel.

Surgical exposures will be palatal or buccal, depending on the position of the crown of the unerupted tooth.

In general, it is important to avoid unnecessary or excessive removal of bone and preserve as wide an area of attached gingiva as possible. Ideally it is desirable to bring the cusp of the canine, on eruption, through the alveolar crest, thereby simulating a normal path of eruption and producing the correct gingival contour and morphology. Few problems are encountered with palatal exposures where an abundance of attached gingiva is found.

Palatal canines

Palatally placed canines may be exposed by removal of soft and hard tissue directly over the unerupted crown. A suitable pack is inserted and left for one to three weeks to prevent re-epithelialisation over the exposed tooth. An attachment should be bonded following pack removal: it is unnecessary to bond a palatal attachment in the operating theatre.

The acid-etch technique for direct bonding of attachments has minimised the amount of tooth exposure necessary. Pins, lassos, cemented bands, cast crowns and preformed inlays have been methods of attachment used prior to the direct bonded attachment.

Occasionally none of the crown of a palatal canine or only a minimal amount is visible after pack removal. Although it is advisable to warn the patient that a re-uncovering could be required, the canine usually erupts. Progress of eruption should be monitored visually (and the amount of erupted tooth recorded) or with standardized radiographs if none of the crown is to be seen.

Labial canines

Boyd (1984) compared two surgical techniques for mild to moderately impacted labial canines. The first was the window technique of exposing the entire labial aspect of the crown and the other a more conservative technique of exposing only 4-5 mm of the incisal aspect of the crown whilst maintaining 2-3 mm of keratinized tissue on the labial aspect. Patients in whom the window technique was used had more gingival recession, gingival inflammation and loss of attachment on the labial and labio-proximal surfaces of the impacted teeth than the other group.

Fig. 6. Direct surgical exposure of a labially impacted canine which was positioned above the mucogingival junction. There is no attached gingiva and inflammation is present in the cervical marginal tissues.

The patient in Figure 6 had a wide exposure directly over the crown of the labially impacted canine which lay above the muco-gingival junction. As a result, there is no attached keratinized gingiva and inflammation is present in the cervical margin tissues.

Mild impactions

Where a large part of the unerupted crown is occlusal to the muco-gingival junction Boyd (1984) recommends an excisional procedure. This involves exposing 4-5 mm of the crown for a direct bonded attachment leaving 2-3 mm of keratinized tissue between the apical border of the excision and the mucogingival junction.

Moderate impactions

Where a simple excision would not leave keratinized gingivae Boyd (1984) advises raising a flap from the keratinized tissue over the tooth and the ridge and then repositioning the flap apically until 4-5 mm of the cusp tip was uncovered. Then the flap is sutured. Vanarsdall and Corn (1977) have described the technique in detail.

The patient in Figure 7 had an apically repositioned flap procedure performed ten weeks earlier and, in contrast to the patient in Figure 6, there is adequate healthy keratinized gingiva.

Fig. 7. Surgical exposure of the labially impacted canine was carried out ten weeks earlier, employing an apically repositioned flap. Healthy keratinized attached gingiva is present.

Severe impactions

Canines which are lying high above the muco-gingival junction are most suitably exposed by reflection of a labial flap from the gingival margin, direct bonding of an attachment followed by replacement of the flap. A fine wire or chain is brought from the bonded attachment on the tooth to the alveolar crest through the incision line. It is used to draw the tooth towards the occlusal plane. This method was recommended by Hunter (1983b) in order to obtain an acceptable muco-gingival junction. However, the technique involves direct bonding of the attachment in the operating theatre, and this may be time consuming, particularly if the technique is unpractised.

Bowker (1991) advocated the use of glass ionomer cement bonded to the crown of the buried canine instead of a surgical pack being inserted over the exposed crown. He stated that the cement can be left in place for at least four months if necessary and it is well tolerated by the tissues. Because the glass ionomer plug acts as an extended crown of the buried tooth and encourages eruption while it is retained, it is particularly useful in cases of deeply impacted canines.

Associated extractions

Hunter (1983a) said that where possible any other necessary extractions should be carried out at the same time as the surgical procedures so that repeated general or local anaesthetics are avoided. Although this is a sensible suggestion, it should not be followed automatically, as is explained below.

Premolar extractions

Occasionally impacted canines are ankylosed, and have to be extracted. Because of the concern about ankylosis and the difficulties associated with treating ankylosis it is recommended that whenever a case with

impacted canines requires premolar extractions for orthodontic correction the extractions are postponed if possible, i.e. if the premolars are not in the eruption path of the canines, until the canines have been uncovered and are seen to be moving (Parker 1957, Machen 1989).

The patient in Figure 8 had a labially impacted 13 and an overjet (top models). The 13 had been uncovered and all permanent first molars were extracted because they had a poor prognosis. The 13 proved to be ankylosed. It may have moved a little but then the movement ceased and instead the adjacent teeth commenced to intrude (middle models). The 13 resisted all attempts to be moved further, including surgical luxation, and had to be extracted. The bottom models show the final result. Jacobs (1989a) has reviewed the literature on ankylosed permanent teeth.

Deciduous canine extractions

The deciduous canines should be preserved, if possible, to prevent the patient having considerable gaps in the dentition for an extended period.

Third molar extractions

If the patient has impacted third molars and is in the late teenage years or older and will require a general anaesthetic for the surgical treatment of the canines, it may be appropriate to remove the third molars at the same time that the canines are undergoing a surgical procedure.

Repositioning

When exposure and orthodontic alignment are not feasible, surgical re-positioning has been suggested (Holland 1955, Richardson and McKay 1983). The unerupted tooth is not removed, it is swung into position pivoting around the neuro-vascular bundle at the apex after removing bone and soft tissue along the required path of movement.

Fig. 8. Top models - 13 has been uncovered and the permanent first molars extracted. Middle models - 13 is ankylosed and adjacent teeth are intruding. Bottom models - finished result after extraction of 13.

Richardson and McKay (1983) had 78 per cent complete success with this method - 22 per cent were short of the occlusal level. Some were subsequently brought down by orthodontic means, some could not be brought down.

Surgical alignment

Surgical alignment is similar to surgical repositioning except that the tooth is brought down, if necessary, to the occlusal plane. An immediate splint is made from tin foil and cold cure acrylic.

There was a 90 percent success rate in the 400 cases treated by Richardson and Mckay (1983) by repositioning or alignment. However, some had complications such as pulp calcifications, pulp death, internal resorption, external root resorption and ankylosis.

Transplantation

Transplantation (a procedure popularised by John Hunter 1771) may be the treatment of choice particularly for the older patient or if the canine is in an especially unfavourable position for orthodontic alignment. The alternatives are either prolonged orthodontic treatment or extensive restorative/prosthetic procedures to fill the space of the missing canine.

An assessment should be made of:

- the space available to accommodate the canine;
- the possibility of removing the unerupted tooth without damaging it;
- the position of the lower canines, particularly if any over-eruption has occurred (Hardy 1982). Sometimes limited orthodontic treatment is required to make additional space.

Current practice is to avoid any instrumentation of the root, i.e. not to damage the periodontal membrane or cementum and not to root-fill the tooth at the time of surgery. The duration of transfer from the original to the new position should be kept to a minimum. The tooth must not be left in traumatic occlusion but bonded at operation and tied with a sectional arch wire to the adjacent teeth which have been bracketed previously.

The use of fixed orthodontic appliances as opposed to full coverage splints allows early functional stimulation which may prevent replacement resorption and ankylosis (Ferguson 1990).

Root resorption, both inflammatory and replacement resorption, is a recognised complication of transplantation. Some operators institute endodontic measures when radiographs show progress of external resorption (Hardy 1982). Others perform endodontic treatment (calcium hydroxide paste) when the orthodontic fixation is removed. One year later the root canal is permanently filled (Sagne and Thilander 1990). Moss (1975) found that approximately 70 of his 100 cases of transplanted canines had a good prognosis (would remain indefinitely in the mouth). Sagne and Thilander (1990) transplanted 56 canines and had a post-operative control period of 2-10 years (mean 4.7 years). Only 2 of the canines had been lost. They considered the prognosis for the other 54 transplants to be very good.

A two-stage transplant procedure has been described for situations where the impacted canine is obstructing movement of adjacent teeth required to create space for the transplant (Briggs and Burland 1974). In the first stage, the impacted canine is extracted and stored in a buccal supra-periosteal, submucosal pouch until the space is available. The canine is retrieved at a second operation and transplanted in the prepared site in the arch. However, extensive crown and root resorption of the transplant has been reported (Cobley and Roberts 1987).

Orthodontic movement of transplanted teeth is possible (Ferguson 1990).

ORTHODONTIC TREATMENT

Removable appliances

Palatal canines are difficult teeth to procline with removable appliances as they have a very sloping palatal surface and are often incompletely erupted. Frequently their apices are quite displaced and this combined with their pointed incisal edges mean that canines are prone to relapse. It is particularly important that sufficient overbite exists after correction to maintain their new position. There should not be an open contact between the opposing lower canine and premolar through which the maxillary canine crown can move palatally. In addition, canines are often rotated. The difficulties associated with palatal canines are such that removable appliances are rarely suitable to treat them (Jacobs 1989b).

Fixed appliances

Palatal canines

Hunter (1983b) stated that the alignment of the palatal canine involves three separate, but consecutive, stages: eruption, labial movement, apical torque.

Eruption

The first movement of the exposed tooth should be towards the lower arch. This ensures that the crown moves away from the roots of adjacent teeth particularly the incisors, that the greater portion of the crown is exposed (to position the direct attachment in the most advantageous site), and that soft tissue impaction is minimised as the tooth is moved labially.

Eruption may be passive or active. In passive (natural) eruption the tooth is left to erupt over a period of 3-9 months. The eruption should be carefully monitored, to ensure the tooth is not becoming re-covered with epithelial tissues, or being excessively delayed by any tissue which occasionally forms a tight collar round the crown.

Fig. 9. Ballista spring system - activated by ligation to 23. Prior to activation on model's right.

Active extrusion is carried out with fixed appliances frequently employing a palatal arch as well. In the 'ballista spring' system of Jacoby (Figure 9) resistance to movement of the anchor teeth is aided by a palatal arch soldered to the first permanent molars and first premolars. The active component is a small diameter wire bent and tied in such a way that it is unable to rotate in the molar tube. The anterior free end projects vertically and is activated by tying up to the attachment bonded onto the canine (Jacoby 1979). Figure 9 shows the spring on the model's left activated and ligated to 23 and the spring on the right in the non-activated position.

If a fixed appliance is to be used in the lower arch a vertical elastic band running from the maxillary canine to the lower arch may be used to produce extrusion. The elastic is changed daily by the patient and the extrusion is often accompanied by some labial movement. Excessive extrusion should be avoided. If displacement from the line of the arch is minimal, then extrusion is unnecessary, providing the lateral incisor is cleared before labial movement is commenced.

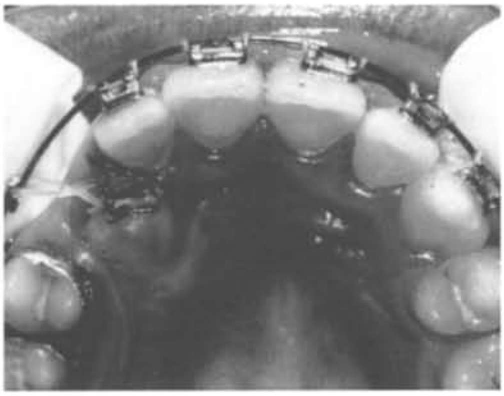


Fig. 10. Elastomeric modules, which are hooked onto the rigid arch-wire, supply the force for labial movement of 13.

Labial movement.

Labial movement is frequently carried out with the use of an elastomeric chain (Figure 10). The direction of the force should be towards the final position of the canine in the arch, and frequently the attachment may have to be resited as the crown moves labially to correct or prevent rotation. Looped arch-wires or sectional arch-wires can be used for labial movement instead of an elastomeric chain.

As the crown approaches the line of the arch, occlusal interference is often produced. If the overbite is minimal 'the bite' may be crossed without difficulty; but if the overbite is deep excessive occlusal trauma will loosen the tooth and impede its movement, and in these instances bite opening is necessary. A lower removable appliance carrying a bite plane provides the required opening. It is important to ensure that sufficient space in the arch is available, or being created, as labial movement occurs.

Figure 11 shows palatal canines being moved labially using a light nickel-titanium arch-wire. A heavy stainless steel arch wire is being used for stability, i.e. to resist the reaction to the labial force on the canine which would tend to move the adjacent teeth palatally. The heavy and light wires share the same arch-wire slot, except that the heavy arch-wire bypasses the canines.

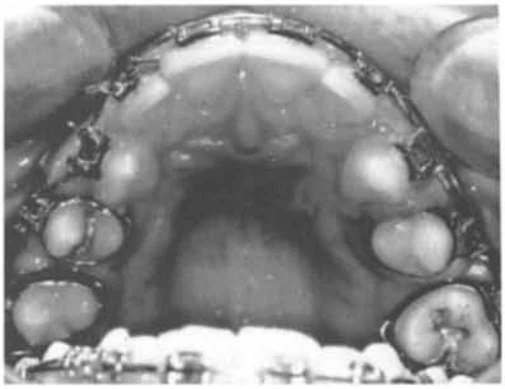


Fig. 11. Palatal canines being moved labially by a light nickel-titanium arch-wire. Stability is provided to the surrounding teeth by a heavier steel arch-wire which bypasses the canines.

Apical torque

For the canine tooth to function, correct axial inclination is essential. If relapse or traumatic occlusion of the canine is to be avoided, the apex must be torqued labially. This final movement is part of the finishing procedures of orthodontic treatment carried out with rectangular wire or auxiliary torquing attachments.

The root of the canine has been torqued labially sufficiently when the palatal gingival margin of the canine is in line with the palatal gingival margin of the adjacent teeth and the root can be palpated on the labial.

Labial canines

Alignment of labially placed canines is simplified since it is unnecessary to cross the occlusion; therefore occlusal interference does not occur. Difficulty arises with the labially impacted canine lying above the mucogingival junction. These teeth may have moved well towards the

mid-line, or have displaced the root of the lateral incisor palatally and therefore lie almost within the line of the arch. In these situations, care must be taken to avoid incisor root resorption when canine movement is started. A direct attachment may be placed at the time of surgical exposure and the crown moved occlusally under the periosteum as described earlier. Alternatively, if the tooth lies very close to the lateral incisor root, labial movement is initially necessary before traction is applied in the occlusal direction, otherwise the lateral incisor root will be damaged. Occlusal movement of the labial canine may be simply produced with an elastomeric chain, and subsequent root torque (to obtain the correct axial inclination) accomplished with the usual orthodontic finishing procedures (Hunter 1983b).

COMPLICATIONS OF IMPACTED CANINES

Complications of leaving canines in situ

Some have been discussed above under Treatment - leave in situ.

Resorption

Ericson and Kurol (1987b, 1988b, 1988c) have investigated resorption of adjacent incisors by impacted canines. They stated that the lesions are often difficult to diagnose with ordinary radiographic techniques because most of the resorptions are located palatally or buccally in the middle third of the root of the adjacent lateral incisor. In many cases they are concealed by the overlapping canine in periapical radiographs.

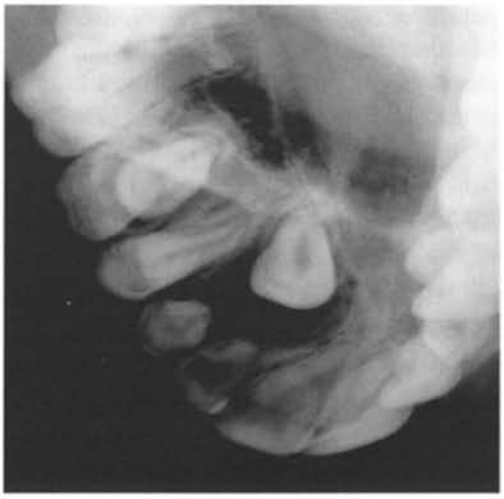
They found that polytomography doubled the number of teeth with diagnosed resorptions compared with intra-oral films and orthopantomograms alone. Tomography also gave a more reliable indication of the extent of the lesions. The use of computed tomography provided a superior image and even more information than polytomography. Resorption of lateral incisors occurs in 12.5 per cent of cases after ectopic eruption of maxillary canines, with a total prevalence of 0.7 per cent for resorbed lateral incisors in the 10-13 year age group.

Resorption of lateral incisors was three times more frequent in females than in males. The impacted canine in resorption cases frequently showed:

- a well-developed canine root;
- the canine cusp erupting medially to the long axis of the adjacent lateral incisor; and
- a mesial angle of eruption to the mid-line exceeding 25°.

In an earlier investigation of 47 resorbed maxillary teeth due to impacted canines, 40 were lateral incisors, 6 central incisors and 1 was a first premolar (Ericson and Kurol 1987a). Six resorbed lateral incisors and the premolar were diagnosed when the patient was aged between 10.1 to 10.9 years. The remainder were aged from 11.0 to 14.9 years). No child reported pain in the region of the canine or the resorbed tooth.

The patient in Figure 12a was aged 12 years 11 months when resorption of 12 was discovered. Subsequently fixed appliances were placed and 13 was uncovered and aligned. The periapical radiograph taken 27 months later at band removal (Figure 12b) shows that resorption did not proceed once the impacted canine was moved away from the root of 12. The 12 was vital at band removal. Non-progression of resorption after removal of the aetiologic factor and that resorbed teeth retain their vitality are frequently reported findings (Kettle 1958, Howard 1970/71).



A

B

Fig. 12a. Occlusal showing resorption of 12. Enlarged follicle evident around 13.

Fig. 12b. Periapical at band removal show resorption has not progressed.

Complications of surgery

- Improper uncovering of labially impacted canines may result in periodontal problems such as a narrow and non-functional labial gingival zone, i.e. no attached keratinized gingiva is present, resulting in the presence of a chronic inflammatory response in the affected oral mucosa (Figure 6).
- Uncovering may result in exposure of the roots of adjacent teeth if the exposure is too broad or access to the crown is limited (Figure 13).
- Repositioning and alignment, as said above, can result in loss of vitality, pulpal calcification, internal and external root resorption, and ankylosis (Richardson and McKay 1983).
- Banding or bonding at the time of surgery may present problems due to limited access and excessive moisture.
- Lassoing can be technically difficult and may result in replacement resorption of the root and ankylosis.
- Pinning too may be technically difficult and can compromise pulp vitality.

Fig. 13. Part of distal aspect of root of peg 22 exposed during uncovering of impacted 23.

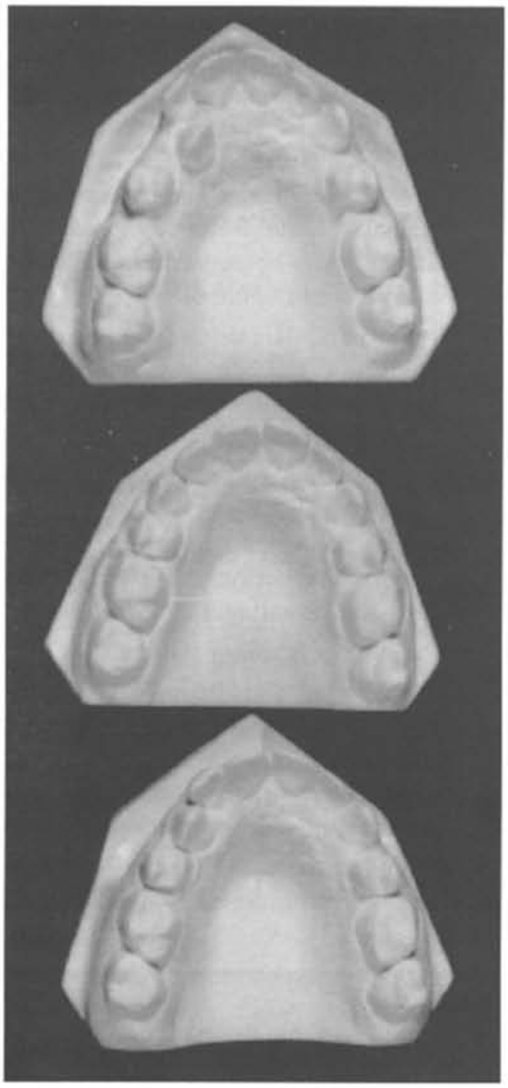


Fig. 14. Top model - 13 has been uncovered and allowed to erupt naturally. Middle model - 13 has been aligned. Bottom model - 13 has relapsed.

Complications of orthodontic treatment

Relapse of treated palatal canines can occur. The models in Figure 14 show a surgically exposed palatal canine (top) which was brought into the line of the arch (middle) and subsequently relapsed to some degree (bottom). Clark (1971) suggested that palatal drift of canines after correction can be eliminated by cutting a crescent, half-moon piece of tissue from the lingual aspect of the moved canine. The cut is made 4 mm from the lingual aspect of the crown and tapers off distal to the lateral incisor and mesial to the first premolar. The tissue is removed to the bone and the opening is packed for ten days.

CONCLUSIONS

The successful treatment of impacted canines involves a team drawn from several dental disciplines. A thorough patient examination is required. There is a range of options for treatment depending on the age of the patient, the position of the canine, alignment and condition of other teeth and the patient's willingness or otherwise to undergo complex orthodontic treatment.

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9
KB Technique

Akira Kameda

INTRODUCTION

A series of modifications has been made to the Begg technique, not only from a diagnostic standpoint but also from a technical standpoint. This modified technique is called KB technique (Kamedanized Begg) and with this KB technique, a fixed favourable result can be achieved. The most important points of the KB technique are: (Table 1) listed in table and will be described in this chapter.

The Most Important Points of KB Technique

1. Horizontal bar's tooth movement
2. Separation of the roles of anchorage bends and bite opening bends
3. Tooth movement with use of ultra light elastic force
4. A way of distalizing of canines
5. Development of by-pass loops pins
6. Development of ribbon arch type buccal tubes for anchor molars
7. Torque and en masse tooth movement during stage II
8. Stage III dropped its burden by transfering into stage II uprighting is the only thing to be done in stage III
9. Quad-diagnosis: establishment of measuring arch length discrepancy and determining extraction sites by means of cephalogram correction

Table. 1.

1. DIAGNOSIS

Quad-Diagnosis

The treatment goal of maxillary protrusion was computed from the average mean of 400 treated cases of Japanese maxillary protrusion, and the treatment goal of mandibular protrusion was calculated based on the average mean of 900 treated cases of Japanese mandibular protrusion (Table 2).

Treatment Goals

Class I and Class II with SN-Mp less than 40°	
U1 to SN	97°
U1 to L1	136°
L1 to Mp	90°
ANB ≤	4°
Class III with SN-Mp less than 40°	
U1 to SN	100°
U1 to L1	130°-140°
L1 to Mp	85°

Table. 2. The treatment goal of maxillary protrusion was computed in 1981 from the average mean of 400 treated cases, and that of mandibular protrusion was calculated in 1982 based on the average mean of 900 treated cases.

If SN-Mp in the average maxillary protrusion case is between 30° and 40°, the treatment goal would be determined to be at L1 to Mp 90°, U1 to SN 97°, U1 to L1 136°, and ANB less than 4°. Where SN-Mp in the maxillary protrusion cases is more than 40°, the treatment goal should be determined by reducing the SN-Mp within the limits of U1 to SN 10° and L1 to Mp 10° (Fig 2) and also, in case SN-Mp in the maxillary protrusion cases is less than 30°, the treatment goal should be determined by increasing the lacked amount of SN-Mp with in the limits of U1 to SN 5° and L1 to Mp 5°.

If SN-Mp in the average mandibular protrusion case is between 30° and 40°, the treatment goal would be L1 to Mp 85°, U1 to SN 100°, U1 to L1 130-140°. The FHP of diagnostic triangle by Tweed *(reference chapter 6)* was changed for SN- Plane and upper incisor axis was joined further to become the diagnostic square and is called Quad Diagnosis.

The procedures of Quad-Diagnosis will now be explained (Fig. 1-3, Table 3 and 4). This is a maxillary protrusion, Angle Class I (Fig 1), and a High angle case showing ANB 4°, SN-Mp 42°, U1 to SN 113°, L1 to Mp 91°,U1 to L1 115°.

As SN-Mp is more than 40°, the treatment goal would be ANB less than 4°, L1 to Mp 88°, U1 to SN 95°, U1 to L1 136°, and the obtained cephalogram correction showed (-) 6mm in the upper and (-) 2mm in the lower (Fig 2).

Fig. 1. A maxillary protrusion, Angle class I case.

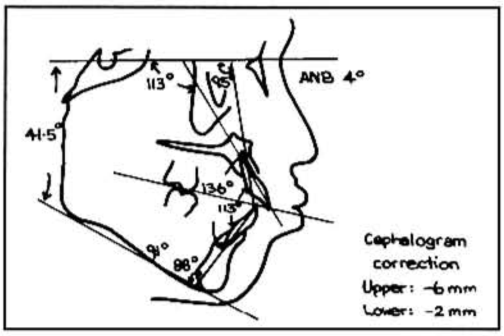


Fig. 2. Cephalogram correction: As SN - Mp is more than 40° in this case, the treatment goal would come to be aimed at some where around ANB less than 4°, L1 to Mp 88°, U1 to SN 95°, U1 to L1 136°, and the obtained cephalogram correction showed (-) 6mm in the upper and (-) 2mm in the lower.

	Before	After
SNA	83°	83°
SNB	79°	79°
ANB	4°	4°
SN - Mp	42°	42°
U1 to SN	113°	93°
L1 to Mp	91°	83°
U1 to L1	115°	139°

Table. 3. A high angle case showing SN - Mp 42°, ANB 4°, U1 to SN 113°, L1 to Mp 91° and U1 to L1 115°.

These data multiplied by 0.9 was reproduced on the patient's plaster models to determine available space in the upper arch as well as in the lower. The sum total of the mesiodistal widths of dental crowns from the second premolar through the opposite side of the second premolar is taken as required space, thė discrepancy between the available space and the required space in the upper and the lower is calculated. The arch length discrepancy in the upper indicated (-) 12.8mm and the arch length discrepancy in the lower showed (-) 7.5mm (Fig 3).

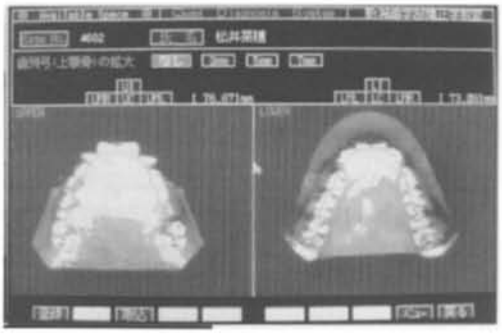
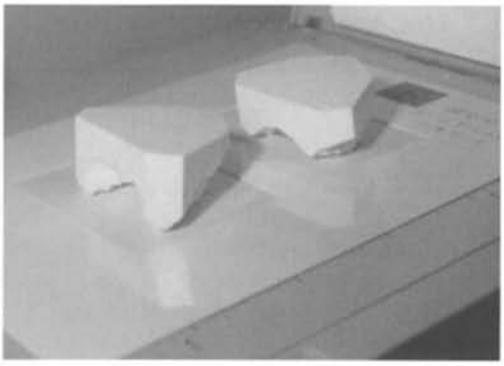


Fig. 3. Arch length discrepancy in the upper and lower is calculated separately and also determination of extraction sites in the upper and lower is automatically made by Quad Diagnosis System. In this case arch length discrepancy in the upper indicated (-) 12.8mm and is the lower showed (-) 7.5mm.



The first premolars are extracted if the arch length discrepancy is less than -9mm, either the first premolars or the second premolars extracted when the arch length discrepancy ranges from -9mm through -6mm, and the second premolars extracted when the arch length discrepancy ranges between -6mm and -3mm (Table 4).

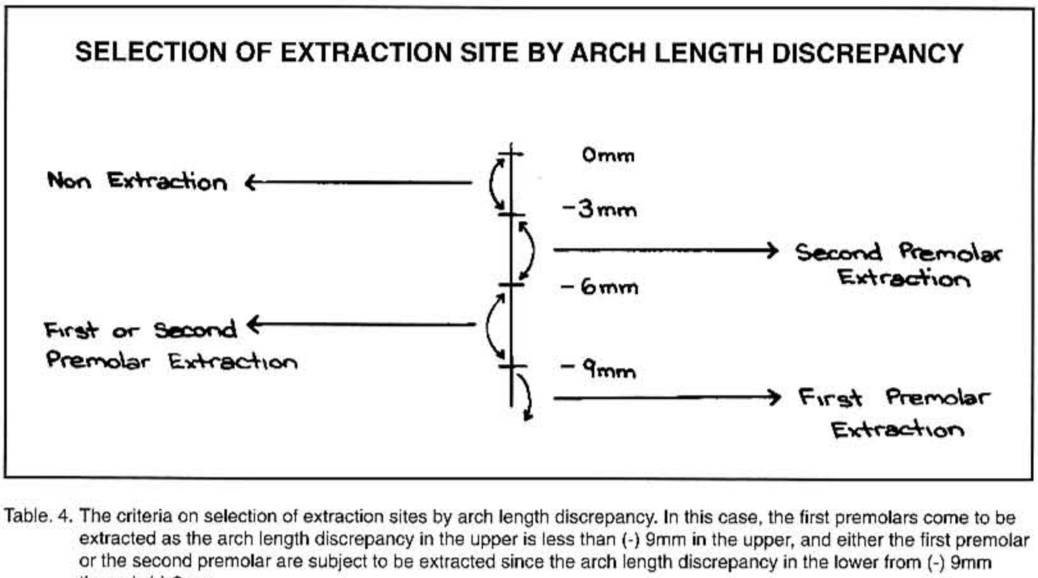


Table. 4. The criteria on selection of extraction sites by arch length discrepancy. In this case, the first premolars come to be extracted as the arch length discrepancy in the upper is less than (-) 9mm in the upper, and either the first premolar or the second premolar are subject to be extracted since the arch length discrepancy in the lower from (-) 9mm through (-) 6mm.

Selection of Extraction Site

Arch Length Discrepancy	Anchorage Value	Growth Tendency	Soft Tissue Analysis	Organised Occlusions

In this case, the first premolars are extracted as the arch length discrepancy in the upper is less than (-) 9mm, and either the first premolars or the second premolars extracted since the arch length discrepancy in the lower ranges from (-) 9mm through (-) 6mm. If one is at a loss as to which teeth should be extracted, particularly either the first premolars or the second premolars, the following factors must be taken into consideration.

1. The size of arch length discrepancy
2. Anchorage value
3. Growth tendency
4. Soft tissue analysis
5. Organised occlusions

One must make allowances for these five factors and to be more specific.

1. Is orthodontic treatment for adults or for children?
2. Is the case with a high angle or with a low angle?
3. How much extrusion of anchor molars will be expected due to the effect of a combination of intermaxillary elastics and anchorage bends (Fig 4)?
4. What is the size of ANB? and which direction the mandible grows?
5. What is the degree of the transformable state of maxillary alveolar process (Fig 5)?

High Angle Case (SN-Mp > 40°)
or
Low Angle Case (SN-Mp < 30°)?

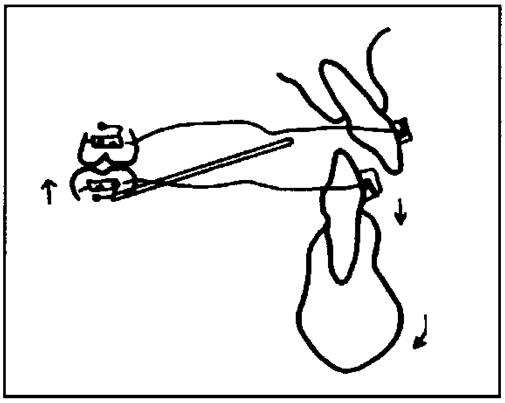


Fig. 4. Extrusion of anchor molars will be expected due to the effects of a combination of strong intermaxillary elastics and large anchorage bend.

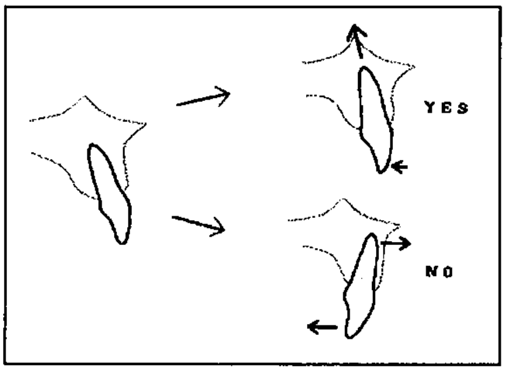


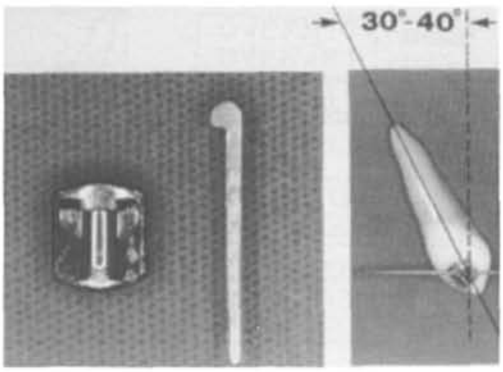
Fig. 5. It is preferable to depress the root apex of upper incisors to wider areas of trough of cancellous alveolar bone and then move them lingually (YES)

2. STAGE I: LEVELLING & BITE OPENING

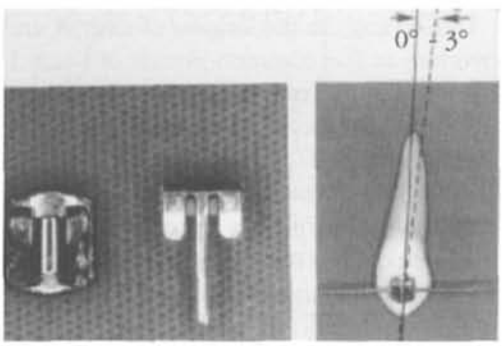
Horizontal bar's tooth movement

Most malocclusions are not composed of mesiodistally displaced teeth but made up of labiolingually inclined teeth, therefore, it is not necessary to carry out orthodontic treatment by tipping teeth mesiodistally.

In order to control unnecessary tipping of teeth, especially mesiodistal tipping, a principle of horizontal bar's tooth movement from Stage I (Fig 6) is used.



Pure Begg - Philosophy of friction free



Revised Begg (Kamedanized Begg)
- Philosophy of low friction

Fig. 6.

A supreme .010" sectional wire or 014", 016" Ni-Ti sectional wire is used in conjunction with main archwires. Locking the wires with Safety T-Pins or New designed Low friction pins will prevent teeth from tipping mesiodistally, but permit teeth to tip labiolingually by taking advantage of round wires (Fig 6AB).

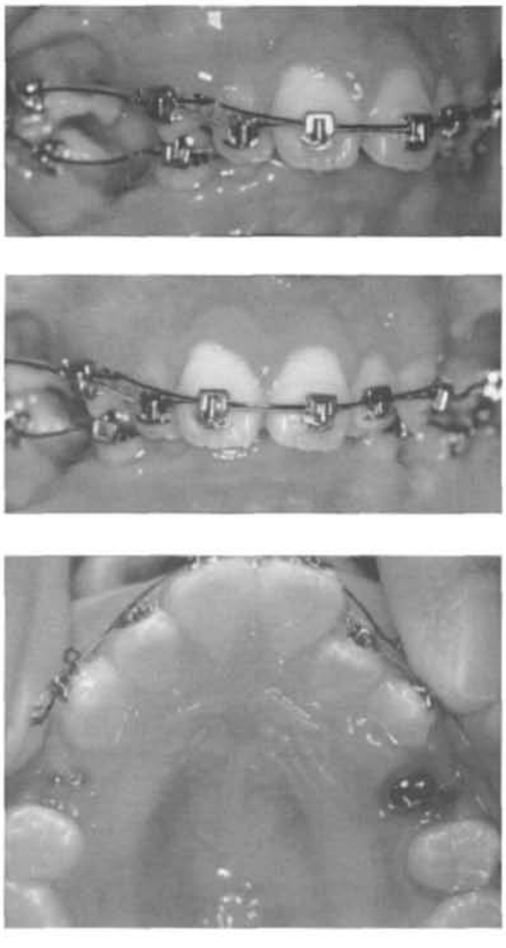


Fig. 6. A - When a supreme .010" or Ni-Ti sectional wire is used in conjunction with main archwires, locking the two wires with low friction pins or T pins will prevent teeth from tipping mesiodistally, but permit teeth to tip more or less labiolingually by taking advantage of round wires.

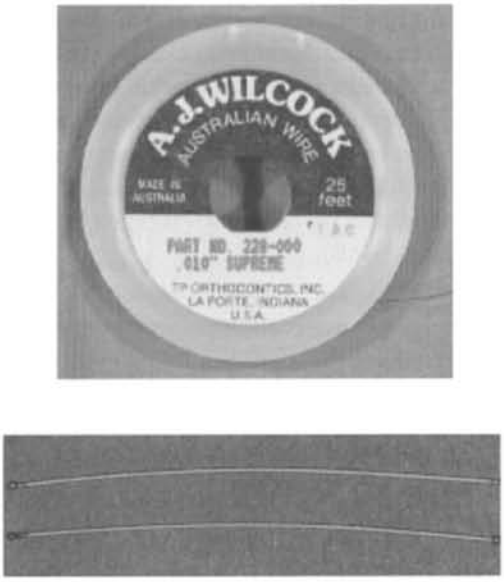
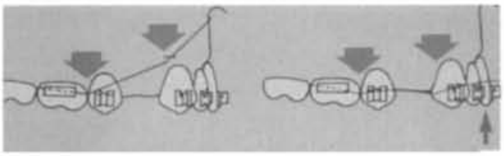


Fig. 6. B - 016" Ni-Ti sectional wires (Rocky Mountain Morita) and 010" supreme light wire (A. J. Wilcock).

Role of Anchorage bend

- stationary anchorage for molars
- bite opening for canines



Role of Bite opening bend

↓

bite opening for incisors

Fig. 7.

Roles of anchorage bends and bite opening bends

In deep bite cases, bite opening bends are placed in archwires distal to canine in addition to molar anchorage bends. While the function of anchorage bends is to anchor molars as well as open canines, the function of bite opening bends is to open incisors (Fig 7). The amounts of anchorage bends during STAGE I~III and bite opening bends to be used during Stage I are demonstrated in (Table 5).

Anchorage Bend
(Anchorage curve)

	016" ESP	018" SP Combination	Ribbon Wire
Maximum	40°	30°	5° (anchorage curve)
Moderate	30°	20°	3° (anchorage curve)
Minimum	20°	10°	2° (anchorage curve)

Bite Opening Bend
(016" ESP wire)

	Upper	Lower
Maximum bite opening	30°	20°
Moderate bite opening	20°	10°

Table. 5.

Ultra Light Class II elastic force

Depending on the degree of overjet and overbite at the commencement of Stage I, Class II elastic force is divided into three steps as follows; No elastics (Fig 8-A), 40-50gr Class II elastics (Fig 8-B) and 60-70gr Class II elastics (Fig 8-C), and ultra light force is used rather than the past light force. In other words, in the event of Class II, div. 1, with a large overjet and also with a large overbite, ultra light force of Class II elastics (40-50gr) is used for about two months at the beginning of Stage I and then, switch Class II elastics on the normal light force; 50-60gr and 60-70gr.

Ultra Light Class II Elastic Force

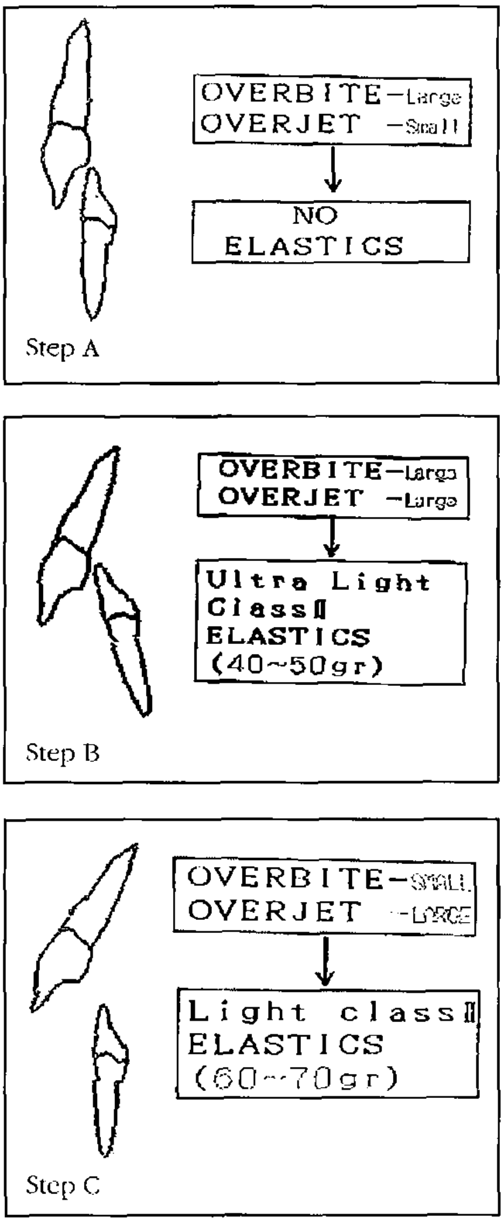


Fig. 8. Depending on the degree of overjet and overbite at the commencement of stage I, Class II elastic force is divided into 3 steps:

A: no elastics.

B: 40-50gr Class II elastics (ultra light elastic force)

C: 60-70gr Class II elastics.

The root apex of upper and lower incisors will be depressed toward wide sites of trough of cancellous alveolar bone if the upper and lower incisors are sufficiently depressed to decrease overbite and then, by lingual inclination of the upper and lower incisors including the alveolar process. A gummy smile will be prevented and the risk of developing root resorptions will be minimised (Fig 9).

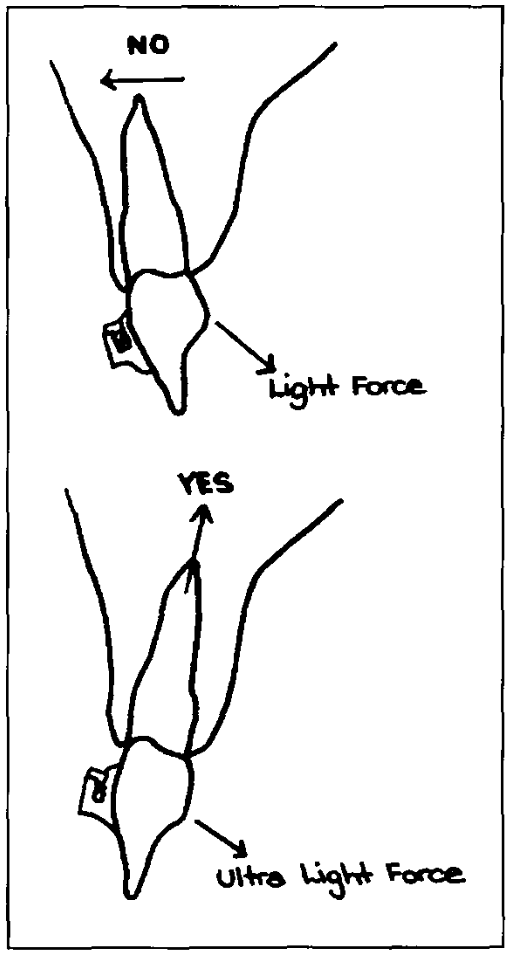
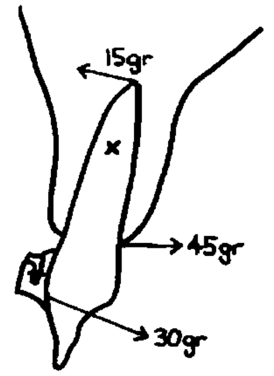
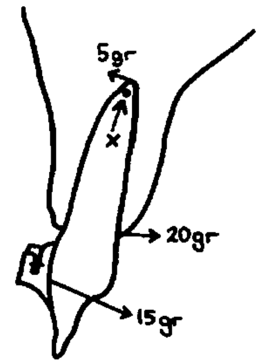


Fig. 9. The apex of upper incisor roots will be depressed toward wide sites of trough of cancellous alveolar bone if the upper incisors are sufficiently depressed to decrease overbite and then, by lingual inclination of the upper incisors including the alveolar process with use of ultra light elastic force, a gummy smile will be prevented and the risk of developing root resorptions will be minimized. (YES)

In case of using light elastic force as shown in Fig 10-A central incisor brackets are subject to about 30 gram's force and this force magnitude is increased by 15 gram to 45 gram for alveolar crest, and about 15 gram is to react on the labial area of root apex, so with root apex moving labially, the centre of rotation will be nearby two-thirds of tooth root closer to the area of root apex (Fig 10-A).



A: Pure Begg - Light Force



B: KB Technique - Ultra Light Force

Fig. 10. A: In case of using light elastic force (pure Begg), central incisor brackets are subject 30 grams force and about 15 grams is to react on the labial area of root apex.

B: On the other hand, in the event of applying ultra light elastic force (KB Technique), about 15 grams force is exerted on central incisor brackets and only 5 gram is to react on the labial area of root apex.

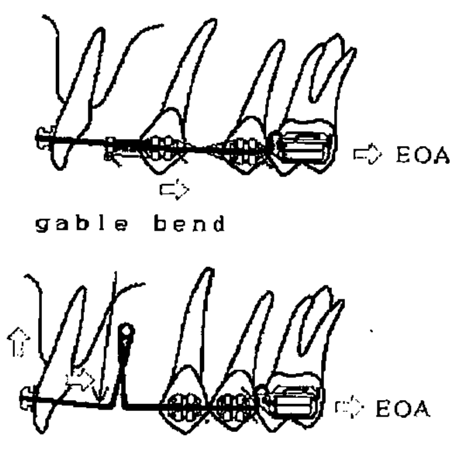
On the other hand, applying ultra light elastic force, about 15 grams force is exerted on central incisor brackets and this force magnitude is increased to about 20 grams for alveolar crest, and only 5 grams is to react on the labial area of root apex. The force magnitude of 5 grams neither causes osteoclasts nor moves the area of root apex labially, therefore, the centre of rotation will be the area of root apex (Fig 10-B).

When starting Stage I, it is preferable to depress the root apex of upper incisors to wider areas of trough of cancellous alveolar bone and then move them lingually.

Way of distalizing canines (Fig. 11, 12)

Also with regard to the way of distalizing canines, it is not to allow the canines to tip distally during Stage I, but it is to move the canines naturally in the distal direction while overbite is being depressed by bite-opening bends. That is, the bite opening of the incisors is conducted with the fulcrum of the canines, and the canines are not allowed to distally tip (Fig. 11B)

Canine retraction



Step A

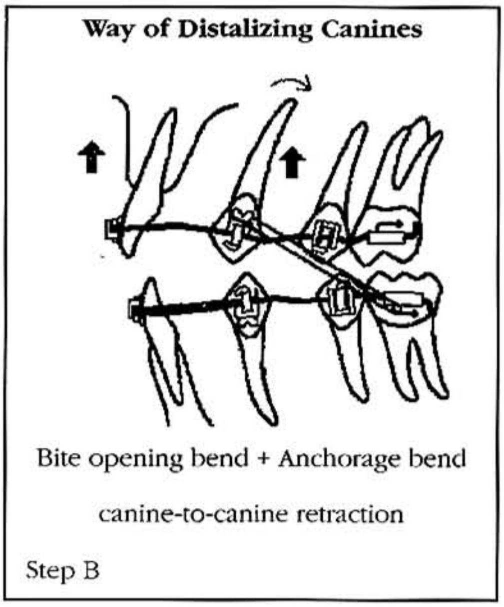


Fig. 11. A: Canine retraction and en masse tooth movement in standard edgewise technique.

B: Canine-to-canine retraction in case of KB technique

In edgewise technique, retraction of canines is first carried out and then en masse tooth movement of incisors from lateral to lateral is conducted with closed looped archwires with gable bends placed distal to lateral incisors (Fig 11-A). The method of retracting canines prolongs treatment time by about 8 months, and spacing between lateral and canine is produced if retraction of canine is carried out, and a tongue habit is likely to develop.

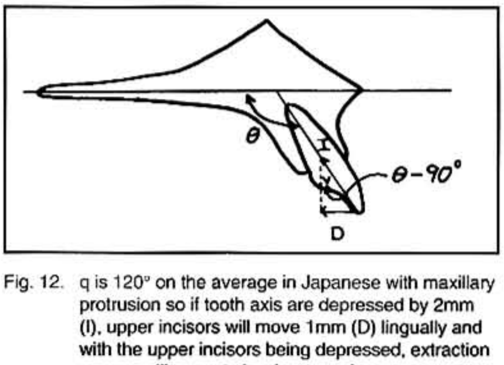


Fig. 12. q is 120° on the average in Japanese with maxillary protrusion so if tooth axis are depressed by 2mm (I), upper incisors will move 1mm (D) lingually and with the upper incisors being depressed, extraction spaces will come to be decreased.

As shown in Fig 12, θ is 120° on the average in Japanese with maxillary protrusion. If tooth apices are depressed by 2mm, upper incisors will move 1mm lingually and extraction spaces will decrease. In the case of upper anterior teeth spaces will result in a decrease of 2.2mm on both side if the incisal edge of incisors is lingually moved by 1mm. Keeping the upper canines upright is better than to tip them distally.

In Stage I, establish an edge-to-edge occlusion and bring L1 to Mp an angle of 85°. Getting close to edge-to-edge occlusions with overjet and overbite in less than 2mm, change upper and lower .016" main archwires for .018" main archwires, and then extend .018" archwires up to second molars (Fig 13).

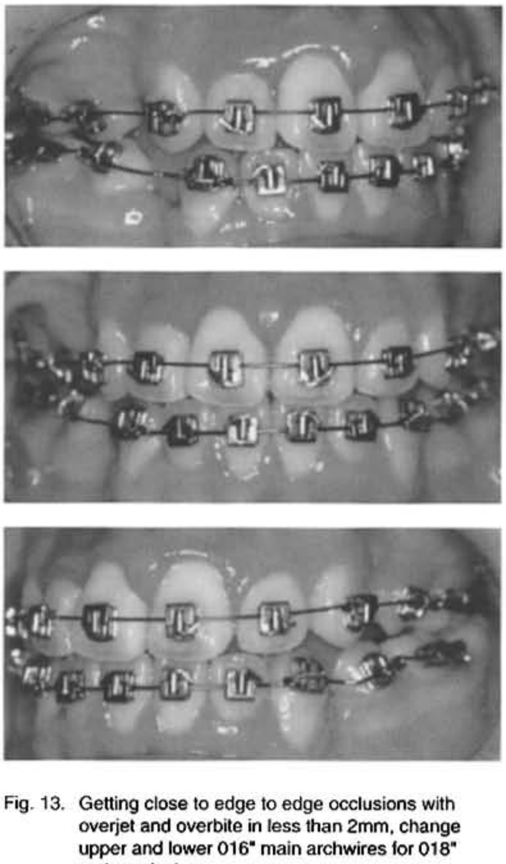


Fig. 13. Getting close to edge to edge occlusions with overjet and overbite in less than 2mm, change upper and lower 016" main archwires for 018" main archwires.

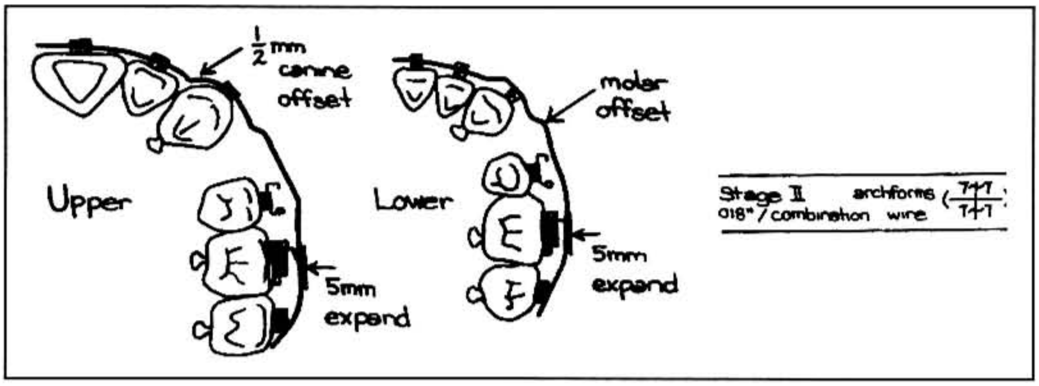
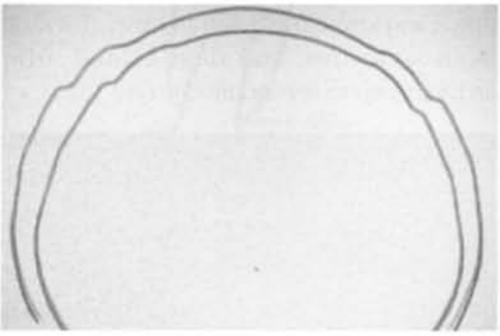


Fig. 14. A

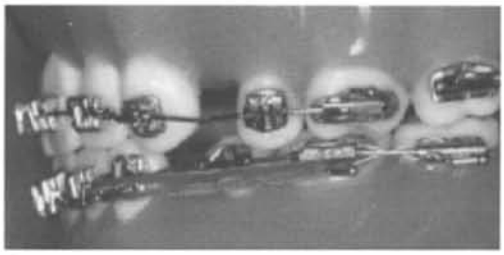


Achorage bend	016"	018"	Combination
Minimum	40°	30°	30°
Moderate	30°	20°	20°
Maximum	20°	10°	10°

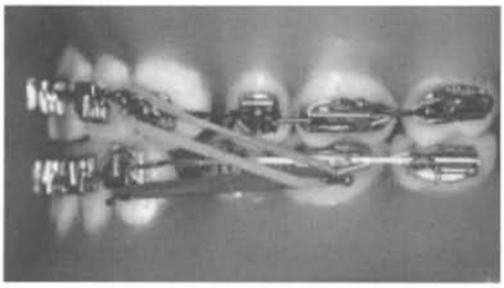
Fig. 14. B - The shapes of archwires including second molars and degrees of anchorage bend.

The shapes of archforms and the degrees of anchorage bends at this moment are as in Fig 14 A, and B.

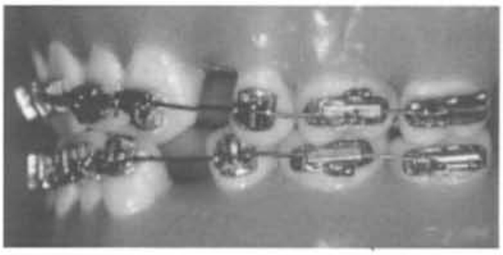
When lower incisors are flared out horizontal elastics are worn only on the mandible to bring the lower incisors to the vicinity of 85° at L1 to Mp (Fig 15-A). Change the lower archwires for combination wires or 0.22" x 016" ribbon archwires to counteract on the side effects of Class II elastics (Fig 15-B). Upper incisors are brought into an edge-to-edge occlusion by Class II elastics at the end of Stage I (Fig 15-C).



A



B



C

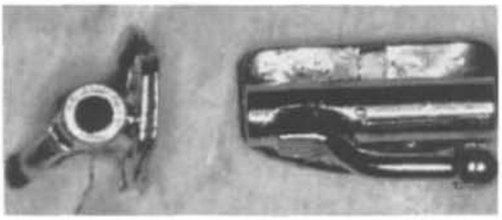
Fig. 15. When lower incisors are flared out (A), horizontal elastics are worn only on the mandible to bring the lower incisors to the vicinity of 85° at L1 to Mp. Change the lower archwires for 022" x 016" ribbon archwires (B) to counteract on the side effects of Class II elastics.

C: At the end of stage I.

By adding the correction of midline discrepancy and the establishment of Class I relation of canines to the treatment goal of Stage I, it is important to conduct Stage I longer than usual.

Philosophy of Friction Free

Round wire + Round tube



Philosophy of Low Friction

Round or Ribbon archwire
+ KB new type tube

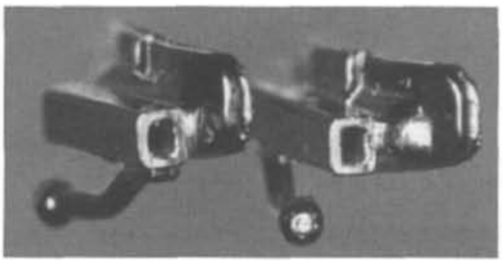


Fig. 16.

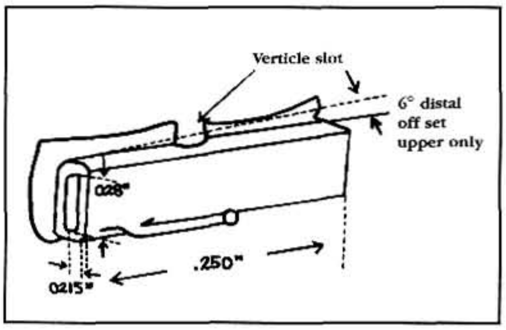
3. STAGE II: SPACE CLOSING & TORQUING.

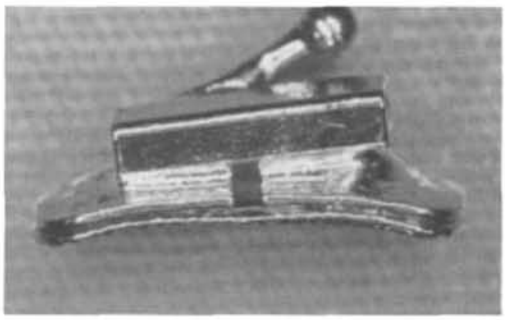
KB buccal tubes

Round buccal tubes with a round wire is friction free (Fig 16). However,

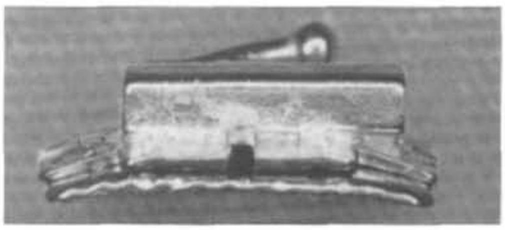
1. Free tooth movement is possible, but anchor molars tend to roll in.
2. Correcting lingually inclined anchor molars is difficult.
3. Directing the forces of anchorage bends and of bite-opening bends is difficult, and the bite-opening efficiency will be decreased.

In order to solve these side effects, a ribbon arch type of buccal tube for anchor molars is used (Fig 17).





For upper anchor molars



For lower molars

Fig. 17. Ribbon arch type of buccal tubes for anchor molars.

The dimension of this buccal tube is as shown in Fig.17 and the inside margin of this new buccal tube is rounded to reduce friction. In addition to a vertical slot, a 6° distal offset is incorporated into the upper buccal

tube only to prevent upper molars from distobuccally rotation in the mesial movement of molars.

Torquing brackets

In maxillary protrusion cases, a 20° torquing bracket is used for upper central incisors and canines and depending on the position of upper lateral incisors at the initial examination, a non-torquing bracket or a 10° reverse torquing bracket or the 20° torquing bracket may be used for the upper lateral incisors (Fig. 18).

As shown in Fig. 19, 10° reverse torquing brackets are used on lateral incisors in a maxillary protrusion case with severely lingual-displaced lateral incisors.

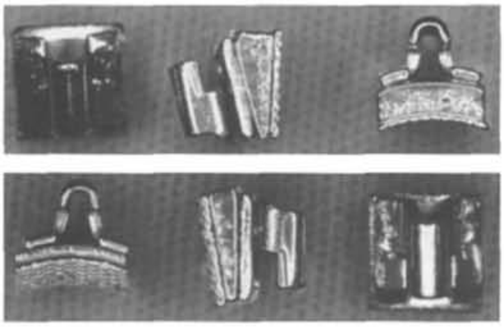


Fig. 18. Brackets (upper and lower) with built in torque.

Fig. 19. Maxillary protrusion case with severely lingual-displaced lateral incisors, 10° reverse torquing brackets are used on lateral incisors.

The 10° reverse torquing bracket is used for lower incisors and canines to counteract on the side effects of Class II elastics. In mandibular protrusion cases (Fig. 20), the 20° or 10° torquing bracket is used for lower incisors and canines and depending on the size of U1 to SN, the 10° reverse torquing bracket or a non-torquing bracket may be used for upper incisors and canines. *That is, non-torquing brackets are used for a case with U1 to SN in less than 100°, and 10° reverse torquing brackets for a case with U1 to SN in more than 100°.*

When these brackets are used in combination with a ribbon archwire, it is possible to torque upper anterior teeth and reverse torque lower anterior teeth in class II malocclusions.

Upper anteriors - reverse torques.

Lower incisors and canines

Fig. 20.

Combination archwire

At present, a combination wire, which is a single wire with anterior section being rectangular and with posterior section being .018" oval, is now being used in stage II, and is available on the market through A.J. Wilcock (Australia) (Fig. 21).

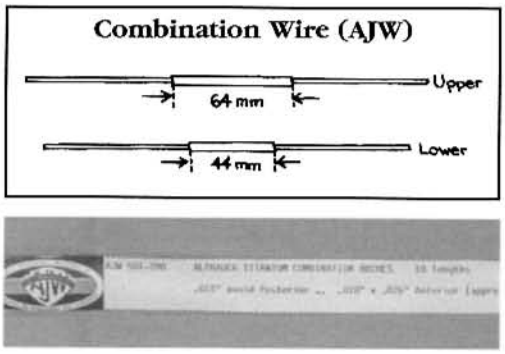


Fig. 21. Combination wire of alpha titanium (A. J. Wilcock)

This combination wire is made of Alpha Titanium, which at 37° C and 100% humidity produces titanium hydride. Thus the wire has the ability to harden in the mouth and shows a very powerful effect as a stabilized wire.

Arch Shaping Pliers for easily and securely bending rectangular wires such as ribbon archwires and combination wires has been developed (Fig 22). The features of a lightwire plier, arch forming plier and cutter were combined and with this plier, canine curves, canine offsets of $^1/_2$ mm and molar offsets can be easily placed in archwires.

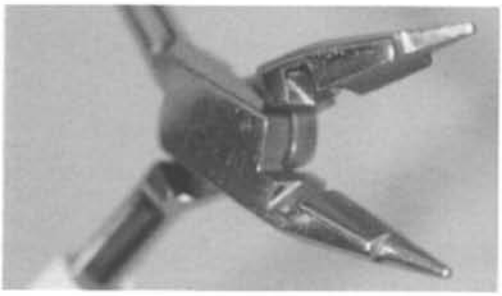


Fig. 22. A.

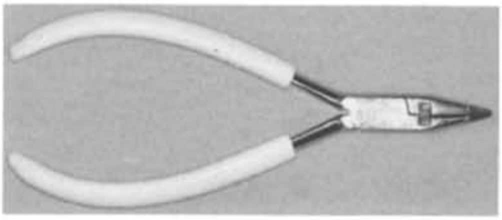


Fig. 22. B - Arch shaping pliers YS 418 (Yamaura Ltd).

Generally, pre-torqued and/or pre-tipped edgewise brackets are common in case of straight-wire techniques, but originally Begg brackets were designed to easy tipping.

Therefore, the strong point of the Begg technique is tipping and the weak point is torquing and based on these features of the Begg technique, torquing and reverse torquing brackets were developed.

If the function of tipping angulation is further built into the brackets, anchorage loss will be great and extra oral anchorage will be required.

Unlike torque with torquing auxiliaries, torque by use of a ribbon archwire and torquing brackets, which brings about crown torquing, has the disadvantage of increasing overjet and developing bimaxillary protrusion.

Fig. 23. In case of torque by use of ribbon archwire and torquing bracket, it is desirable to torque for prevention of the side effects while a little extraction spaces remains.

To protect anchorage, therefore, it is desirable to torque for prevention of the side effects while a little extraction space remains. (Fig 23)

From a biological aspect, therefore, it is correct to make the tooth roots parallel by uprighting them after bringing their tooth apex into the neutral position of trough of cancellous alveolar bone.

It is important to correct the labiolingual position of the tooth roots by torquing during Stage II to prepare conditions when the tooth roots can be effectively uprighted during Stage III.

KB Technique

Stage II
Torquing and Space Closing

Original Begg

Stage II
Space Closing

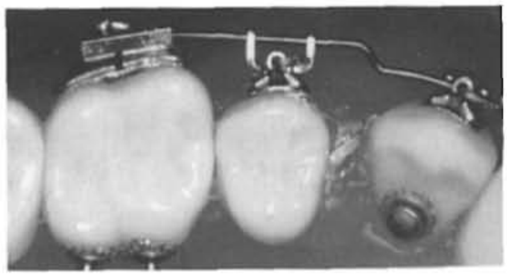
Stage III
Torquing and Uprighting

By-Pass Loop

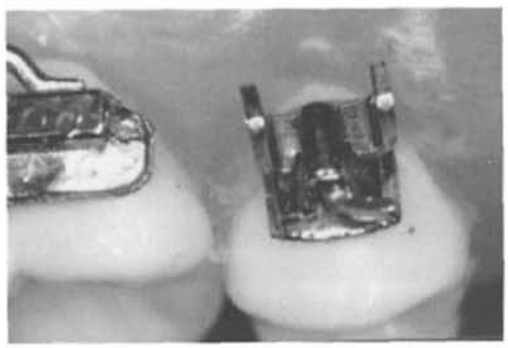
The most important thing in closing extraction spaces is three-dimensional control of second pre-molars. That is to prevent second premolars from subsiding, from rotating and also from mesially inclining, when closing extraction spaces. A By-Pass Loop (Fig 24) is used instead of conventional By-Pass Clamp.

Second pre-molars are safely by-passed when By-Pass Loops are locked into the second pre-molar brackets (Fig. 25).

A



B



C

Fig. 24. By pass loop pins (Biodent - Yamaura, TP orthodontics).

Torquing and en masse tooth movement

As regards torque and en masse tooth movement of upper and lower incisors and canines, E-links or a .010" sectional supreme light wire (A. J. Wilcock Australia) is inserted into brackets from canine to canine to maintain a distance between canines, and then a ribbon archwire is put into buccal tubes through By-Pass Loops and locked with T-pins in brackets (Fig. 25).

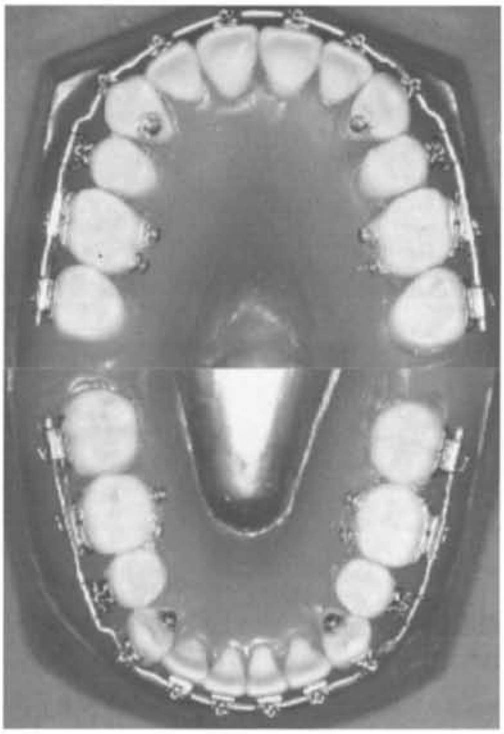
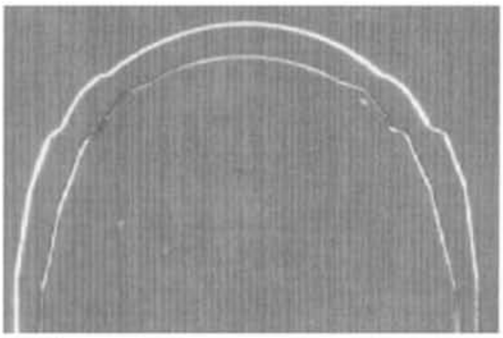


Fig. 25. 2nd premolars are safely by passed when By-pass loops are locked into the second premolar brackets.



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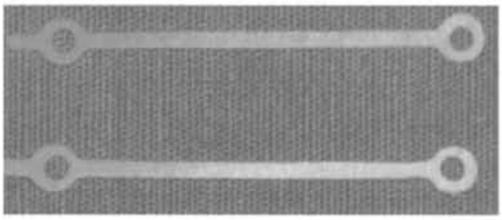

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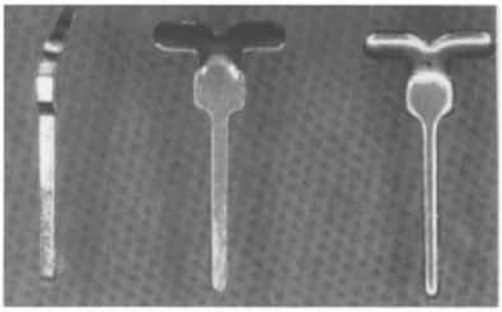

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Fig. 25. A: Stage II ribbon archwires

B: Elinks for canine to canine (Upper: #010, Lower: #009)

C: Power pins as elastic hook.

Unless you place ribbon archwires deep into bracket slots and securely lock them by use of Tweed's parallel beak pliers, the torquing effect made up of the combination of torquing brackets and ribbon archwires will be impaired (Fig 26).

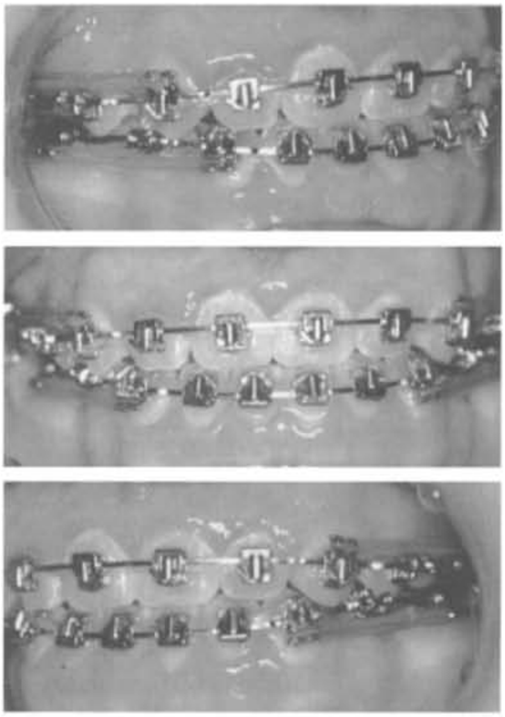


Fig. 26. Procedures of stage II with rectangular wires (022" x 016") and torquing brackets.

By use of power pins to be slipped lingual to the ribbon archwire with T-pins, elastics can be hooked without circle hooks. In principle, the position of incisor edges can be held by use of horizontal elastics during Stage II, when upper and lower incisors are torqued.

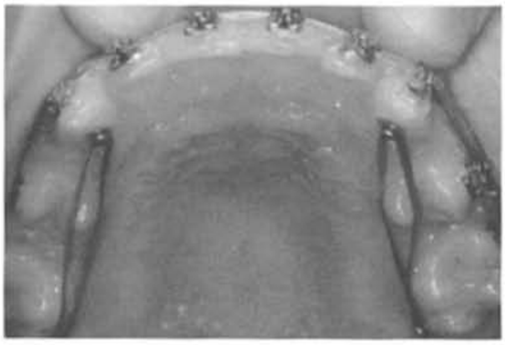
E-links or power chain have been worn from a lingual button on canines to a lingual button on molars both in the maxilla and in the mandible to assist in closing extraction spaces (Fig 27). Also, it is easier to control the rotation of anchor molars (lower).

Future orthodontic treatment should move in the direction of managing without patients' cooperation as much as possible. In this connection, requests made by patients for betterment of orthodontic treatment are as follows:

a. no extra oral anchorage;
b. no more than 2 years' active treatment time;
c. as simple archwires as possible;
d. an improvement for minimising the size of brackets;
e. minimal use of elastics;
f. no excessive cooperation on patients;

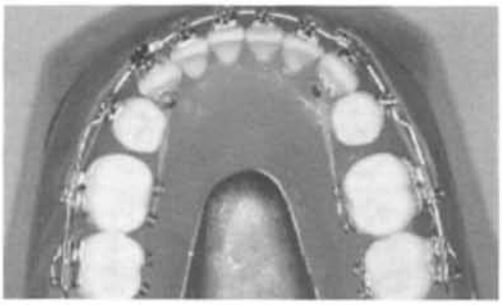
4. STAGE III

Treatment requirements in Stage III are simplified since torque has been already completed during Stage II (Fig 28).



A

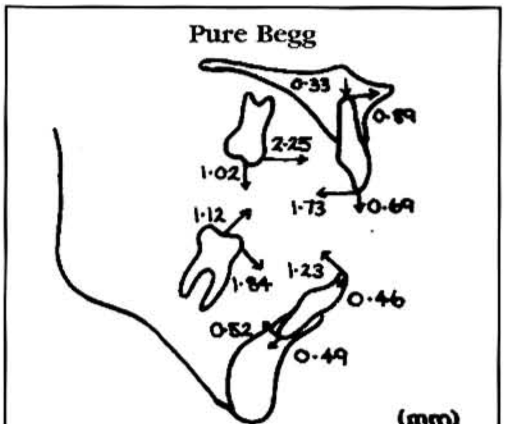
B



C

Fig. 27. A, B, and C - e-links (#005) or power chain are worn from a lingual button on canines through a lingual button on molars, closing extraction spaces.

In this KB technique the amount of tipping of teeth is very much controlled and small from the beginning of treatment through the end of Stage II and as shown in Fig 29, the tipping of canines and premolars next to extraction spaces is about 4 - 7°.



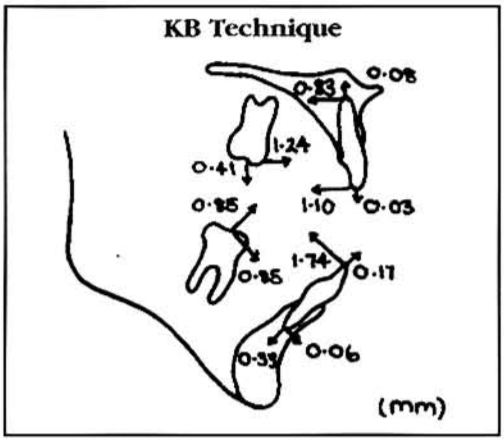


Fig. 28. Tooth movement during Stage II. (pure Begg vs KB technique).

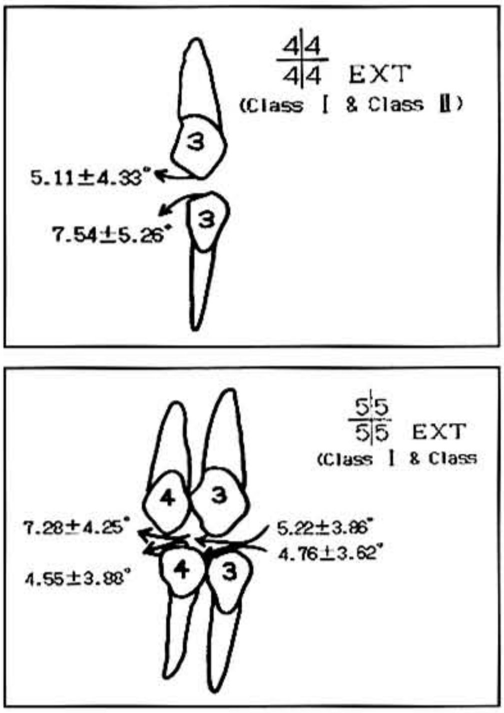


Fig. 29. Distal tipping movement during Stage I and stage II with KB technique. The tipping of canines and premolars next to extraction spaces is about 4-7°.

Therefore, the speed of uprighting with an uprighting spring is about 2.5° per month (Fig 30).

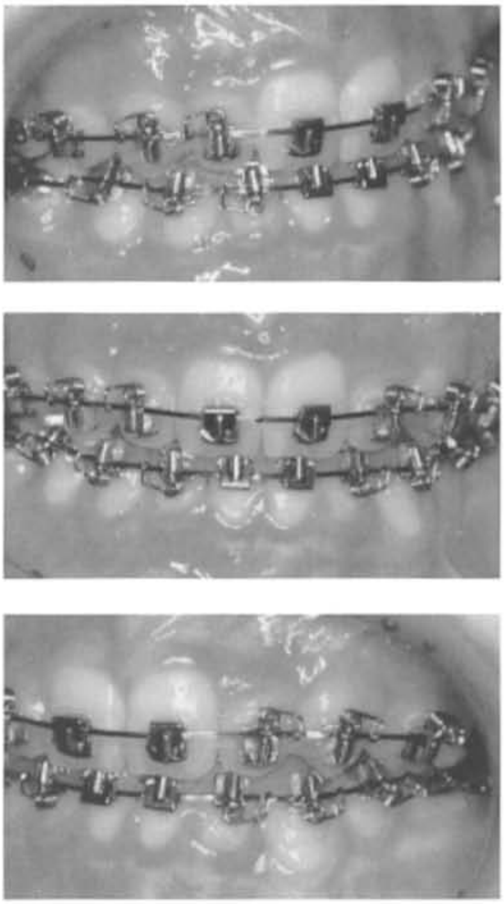


Fig. 30. Stage III: uprighting by means of uprighting springs.

Uprighting by means of uprighting springs is the only thing to be left and once uprighting is completed (Fig 31), active treatment is completed, with 10° T-pins holding the over-uprighted teeth (Fig 32).

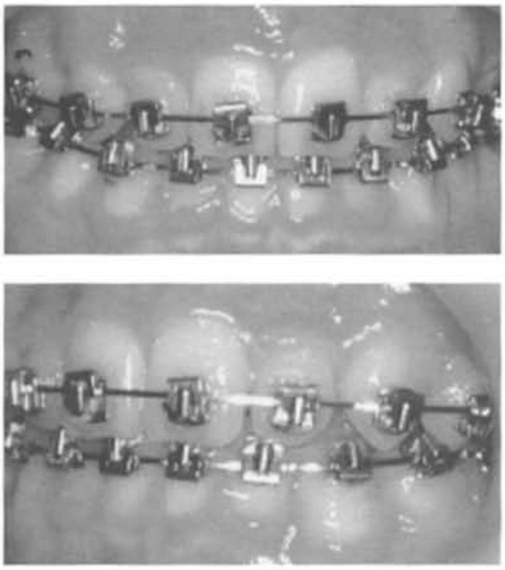


Fig. 31. Finishing stage with 10° T pins.

Fig. 32. End of active treatment.

Treatment Goals of Stage I, II and III

Stage I

↓

Levelling Bite Opening

↓

Round Wire

Stage II

↓

Space Closing Torquing

↓

Combination Wire and/or Ribbon Archwire

Stage III

↓

Uprighting

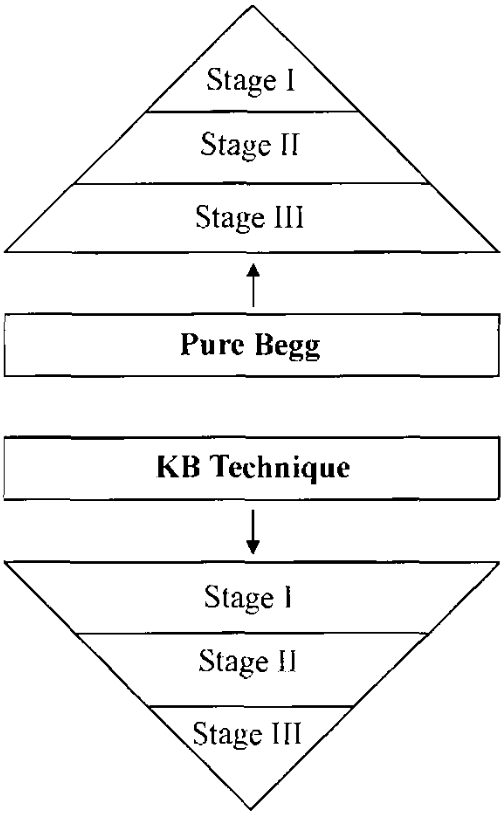
↓

Ribbon Archwire

5. TREATMENT GOALS OF STAGE I, II, AND III

In the event of the pure Begg technique, Stage II is commenced after finishing bite-opening even if the treatment goal of Stage I has not been completely achieved, then proceed with Stage III for torquing and uprighting.

However, in KB technique, the weight of Stage III which used to be complicated and take a long chairtime is simplified by increasing the number of treatment goals of Stage I and by torquing during Stage II and on the whole, operators and patients became feel at ease in reducing the number of things to be done as stage goes by just like a reverse triangle as shown on the next page, and active treatment came to be ended half automatically when operators as well as patients get tired of orthodontic treatment.



There would be more things to be done as stages advance (Top: Pure Begg), KB technique (Bottom), this simplified by increasing the goals of Stage I and torquing during Stage II.

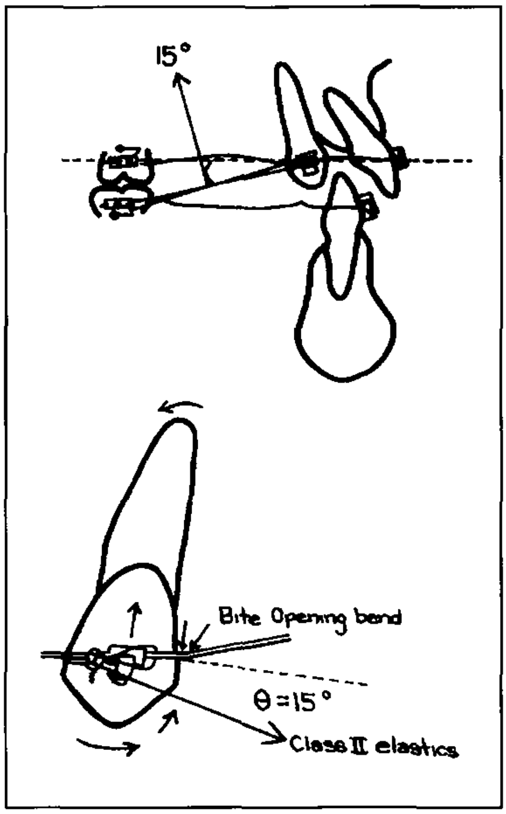


Fig. 33. Class II elastics at 15° to the occlusal plane.

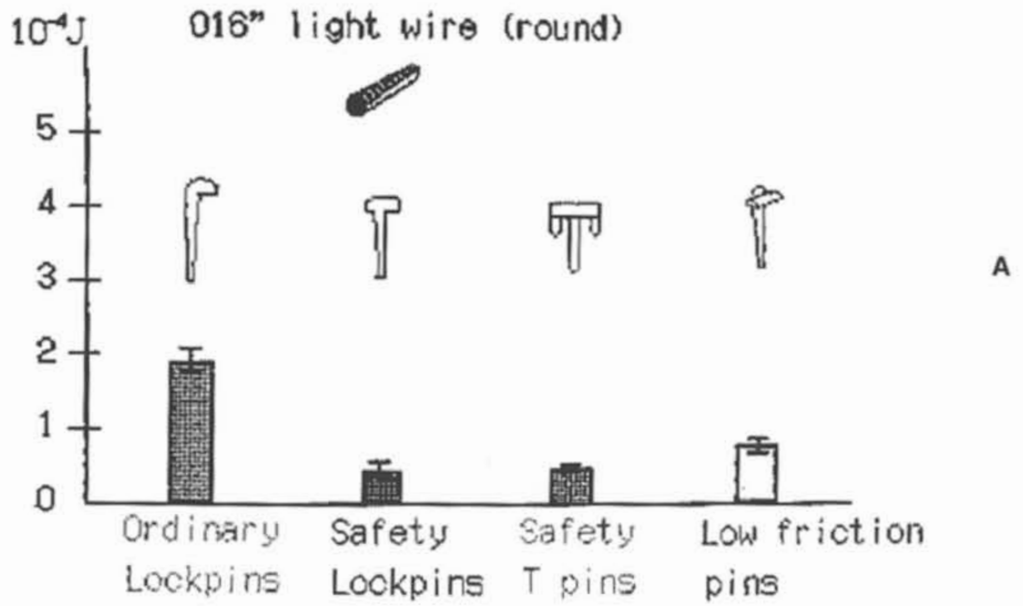
6. KINETIC FRICTION FORCE BETWEEN KB TECHNIQUE AND ORIGINAL BEGG

To make sure if the force system of KB technique is theoretically correct and to determine what anchorage is necessary, the kinetic frictional forces among various brackets, wires and pins were experimentally measured and compared with the pure Begg technique.

The experimental force on the canine bracket was set at 15° to the occlusal plane, so as to reproduce the tooth movement, and then measured the energy of kinetic friction to make a comparative examination.

As the result, the highest kinetic friction was produced when a .016" or a .018" main archwire was locked with ordinary lock pins, and the second highest kinetic friction was caused when locked with low friction pins, the third kinetic friction was yielded when locked with safety T-pins, and the least kinetic friction was brought when locked with Safety Lock Pins.

With .016" or .018" main archwires, however, no significant difference was shown in kinetic friction among Safety Lock Pins, Safety T-pins and Low Friction pins.



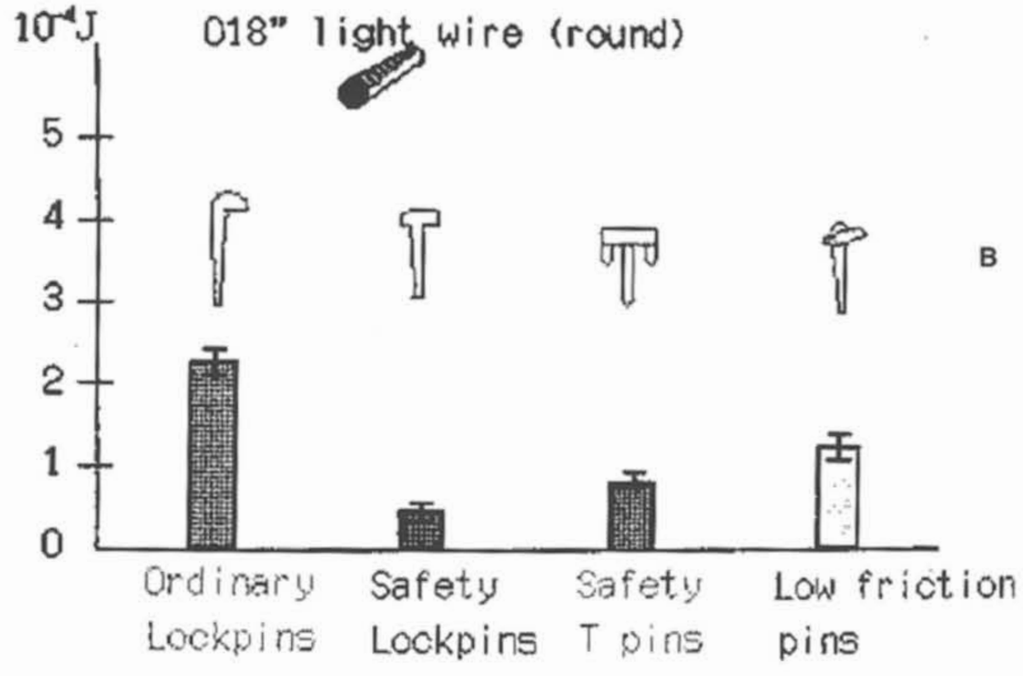


Fig. 35. The highest kinetic friction was produced when a 016" or 018" main archwire was locked with ordinary lock pins (A, B) and the second highest kinetic friction was caused when locked with low friction pins, the third was yielded when locked with safety T pins and the least was brought about when locked with safety lock pins. No significant difference was shown among safety lock pins, T pins and low friction pins.

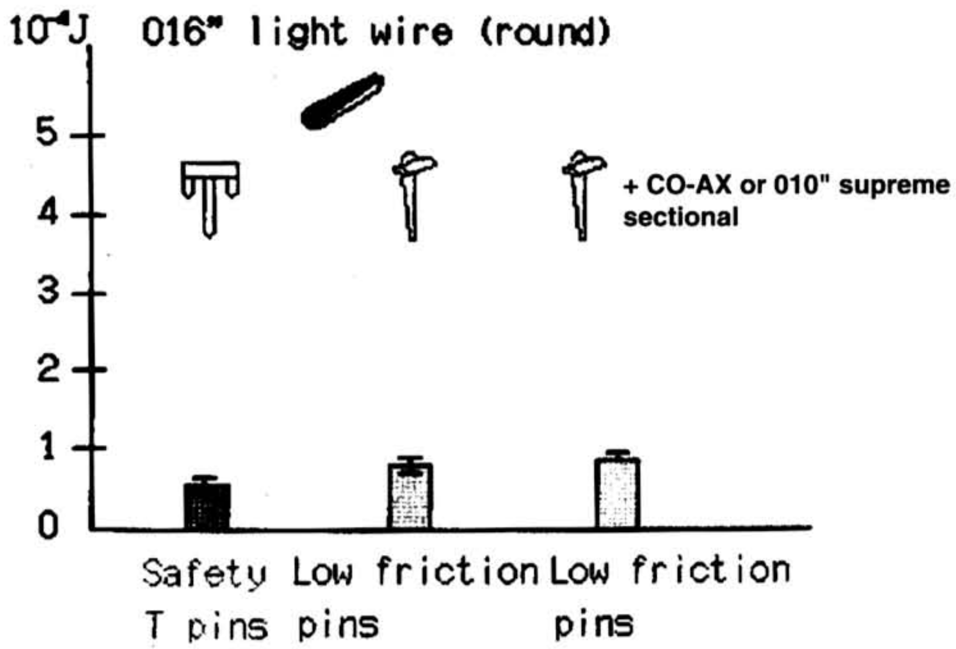


Fig. 36. When CO-AX or 010" supreme sectional auxiliaries is used by a combination of a 016" main archwire and safety T pins or low friction pins, kinetic frictional forces indicated the medium value between the case of locking with safety T pins and with ordinary lock pins (Fig. 35A).

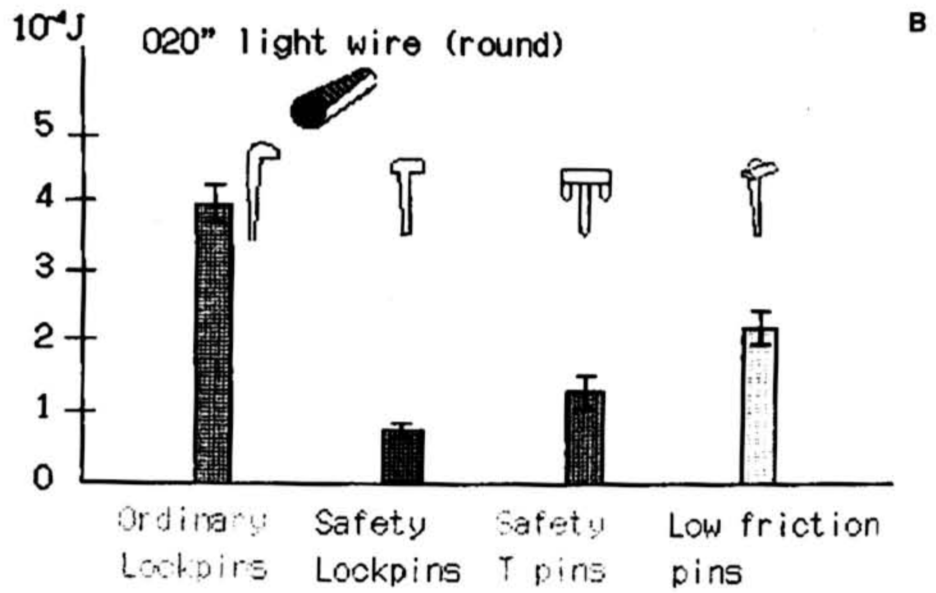
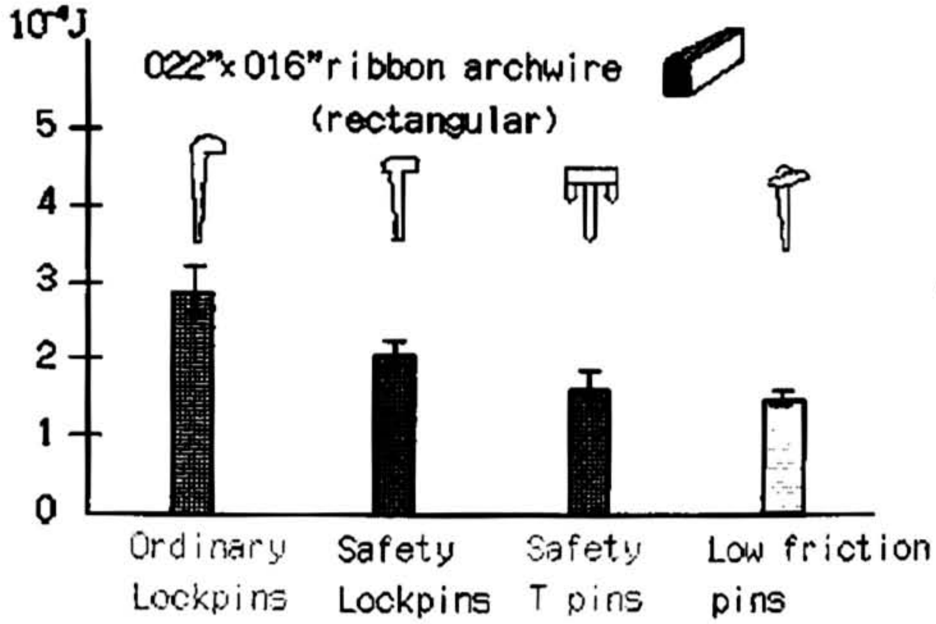
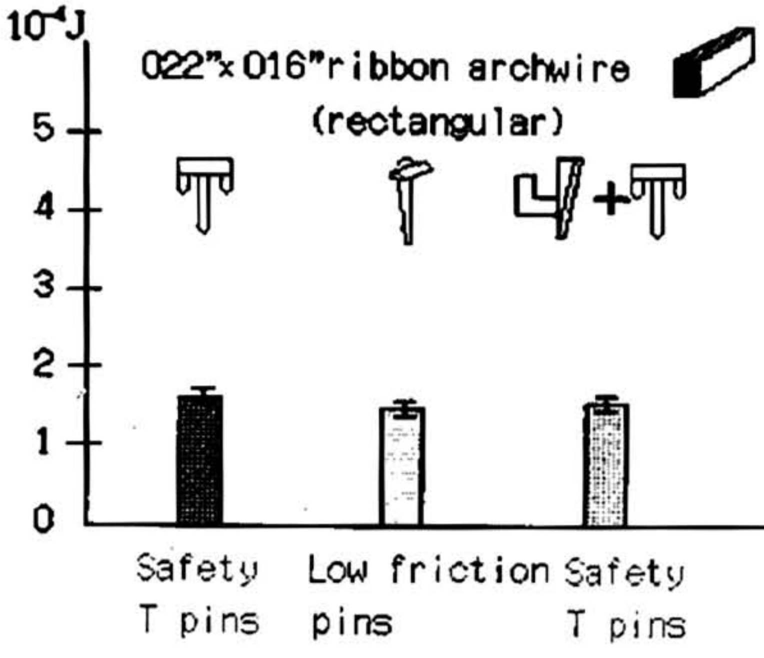


Fig. 37. The kinetic frictional forces among Begg brackets, 020" light wires and lock pins or other non-tipping pins (T pins or low friction pins).



A



B

Fig. 38. A: The kinetic frictional forces among Begg brackets, 020" x 016" rectangular wires and lock pins or other non-tipping pins (T pins or low friction pins).

B: The kinetic frictional forces among torquing brackets, 022" x 016" rectangular wires and T pins or low friction pins.

If Co-Ax auxiliaries, a .010" supreme sectional light wire or Ni-Ti sectional wires is used only by a combination of a .016" main archwire and Low Friction pins, almost the same tendency for kinetic friction was shown, which indicated the medium value between the case of locking with Safety T-pins and with ordinary lock pins (Fig. 35A).

Whichever pin might be used to lock a .020" main archwire such as Ordinary Lock Pins, Low Friction pins, Safety T-pins and Safety Lock Pins, kinetic friction would be radically augmented (Fig 37).

Compared with this, the highest kinetic friction was demonstrated if a .022" x .016" ribbon archwire was used as a main archwire and locked with Ordinary Lock Pins, the third was when locked with Safety T-pins, and the least kinetic friction was in case of locking with Low Friction pins (Fig 38-A).

When the ribbon archwire was used, there was no difference in kinetic friction between Low Friction pins and with Safety T-pins and that is, in the event of en masse tooth movement by use of a .020" main archwire or a .022" x .016" ribbon archwire with Ordinary Lock Pins or Safety Lock Pins, it is difficult to retract anterior teeth, thereby causing a great anchorage loss of molars (Fig. 37 and 38A).

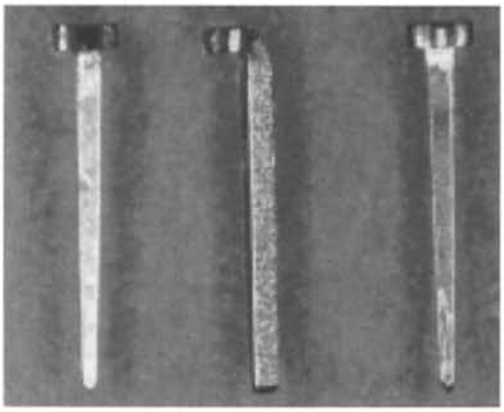
Compared with this, en masse tooth movement by use of a ribbon archwire locked with Low Friction pins or Safety T-pins showed less kinetic friction and a little anchorage loss of molars and furthermore, anterior teeth proved easy to move distally and bodily (Fig 38-A, B).

Torque and control of tooth axies can be securely conducted by combination of a ribbon archwire and torquing or reverse torquing brackets, while extraction spaces remain.

7. IMPROVEMENTS IN THE NEAR FUTURE

Low friction bracket (KB bracket: prototype)

A new prototype of bracket is the KB (low friction) brackets (Fig 39, 40) which has the same function of T-pins has been developed. You don't have to use T-pins to prevent teeth from tipping mesiodistally if these brackets are used and locked with special lock pins (low friction pins: prototype) (Fig 39).



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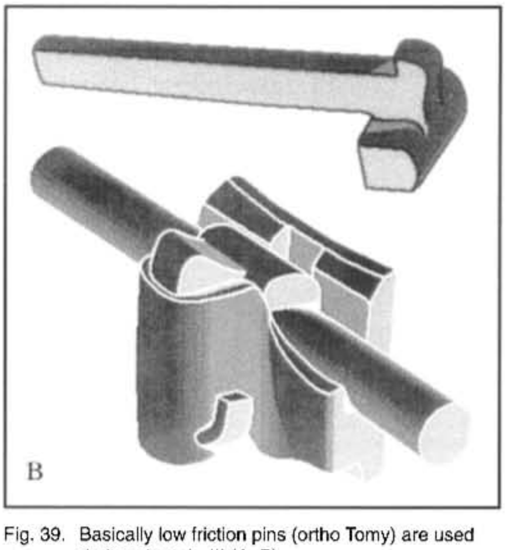
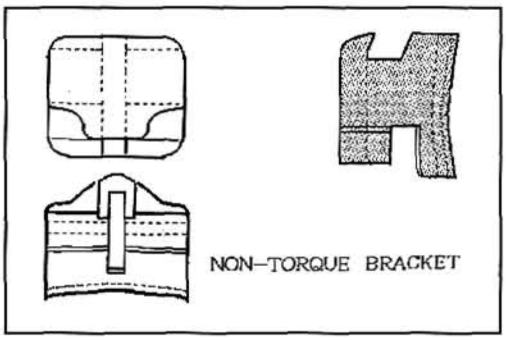


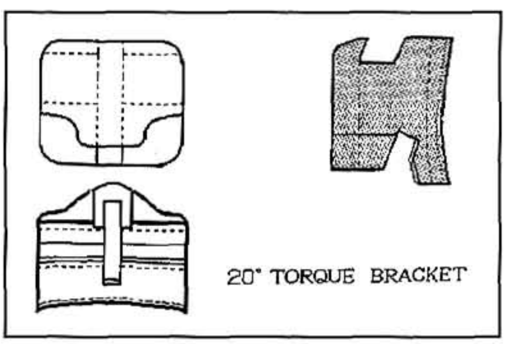
B

Fig. 39. Basically low friction pins (ortho Tomy) are used during stage I - III (A, B).

These new brackets are cast. The labio-lingual thickness of the torquing-based brackets as large as the amount of torque built into their bracket bases. The torquing-based brackets can be obstructive in controlling overjet and overbite (Fig 19, 20). KB brackets (low friction brackets) result in the same as non-torque brackets in dimension without increasing the thickness of the brackets regardless of 20° or 10° torque (Fig 40).

With this, it is possible to manufacture new KB brackets (low friction brackets) with the addition of not only torquing but also tipping angulation in the future.





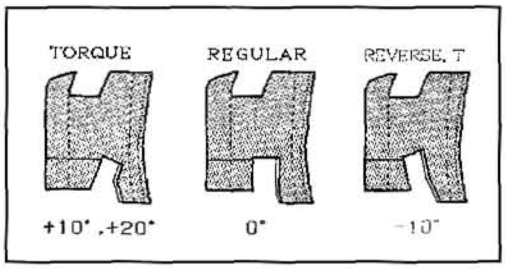


Fig. 40. Low friction bracket (KB bracket), low friction brackets (ortho Tomy: prototype) results in the same as non-torque brackets in dimension without increasing the thickness of brackets regardless of 20° or 10° torque.

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10
The Lingual Appliance

John D Jenner & Bevan G McLean

INTRODUCTION

The practice of orthodontics and its acceptance by the broader community has undergone immense changes in the last two decades. Much of this change has been made possible by the development of new materials which has permitted improved methods of treatment. Consequently orthodontic treatment has become acceptable to a much larger section of the population. The traditional orthodontic band, sealed in place with a cement, has now been replaced with a bracket and end tubes bonded directly to the surface of the tooth. Tooth movements have been dramatically improved as the physical properties of materials such as archwire and elastomerics have improved so that the results of treatment are not only better but the time taken to treat has been reduced and is more predictable.

Twenty years ago the number of adult patients in orthodontic practices was insignificant, but today adults are an important component and their numbers are increasing! (Proffitt1993). The decision taken by adults to commit themselves to the regimen of wearing and displaying orthodontic appliances is a more complex matter than for the younger age groups, as they have the demands of their work and broader social needs to consider. Of those who would accept all other aspects of treatment there is a group which is not prepared to display appliances. Their attitude may be based on the dictates of their work or it may be derived from their personalities. For these patients, lingual orthodontics, as it has come to be known, offers them a solution. Without this option they will remain concerned about their dental state but will not be prepared to proceed with treatment using conventional labial appliances. Fortunately, this group of patients will usually agree to combining a palatal appliance with a mandibular labial appliance. This combination of upper palatal and lower conventional appliance has revealed advantages. It meets the patient's needs, is less costly and the demands placed on the orthodontist are reduced. It also enables the clinician to use the lower arch as a means of judging upper arch progress, particularly when experience with a palatal appliance is limited.

Dr Owen Oliver's development of the labiolingual technique more than fifty years ago is evidence that orthodontists have long been concerned about the appearance of appliances. Tarpley (1961) lists as an advantage of this method that the appearance is inconspicuous "since it is not burdened

with a large number of bands" (2). The appearance of orthodontic appliances was controlled by the orthodontic band until this could be replaced. This was achieved when Professor Muira (1971) presented an acid etch bonding system. Bonding permitted other avenues to be explored to improve the aesthetics of orthodontic appliances, including the use of plastic and ceramic brackets as well as enveloping archwires in tooth coloured materials. What bonding made possible for the first time was the placement of the total appliance on the palatal or lingual surfaces of the dental arches so that it was not seen

DEVELOPMENT OF LINGUAL APPLIANCES

Dr Kinya Fujita (1979) began work on development of a lingual bracket technique in 1971 and published case reports using his method. He claimed in its favour that if the patient has a positive attitude towards treatment, the risk of lip injury is reduced, the site of possible caries development is more acceptable, and because of its location the appliance can be used as a fixed retainer. Since the bracket is placed close to the functional line for orthodontic forces to pass through the centre of resistance, Fujita believed there was relatively little anchorage loss. He saw as disadvantages that treatment may take longer, that speech initially may be affected and that both patient and operator may have to assume awkward positions during treatment.

Dr Craven Kurz (1980) in co-operation with the Ormco Company developed an edgewise bracket for lingual application and began treatment cases in 1980. In order to gain input from additional specialists, the Lingual Task Force was formed in December 1990. Since that time lingual orthodontics has been promoted in courses while some universities in America have included lingual orthodontics in their post graduate teaching programmes.

Both Fujita and Kurz adapted the edgewise mechanism for use on the lingual surfaces. Dr Stephen Paige (1982), who preferred the edgewise appliance labially, recognised that a round archwire technique would be more suitable when applied lingually. The greater variation of lingual surface anatomy meant that a round archwire compared with a rectangular wire was less liable to cause undesirable torque, and therefore the positioning of brackets at precise angulations was less critical. As distinct from the labial approach, the ribbon arch bracket is positioned with the vertical slot directed towards the occlusal surface to facilitate archwire placement (*Fig 1*).

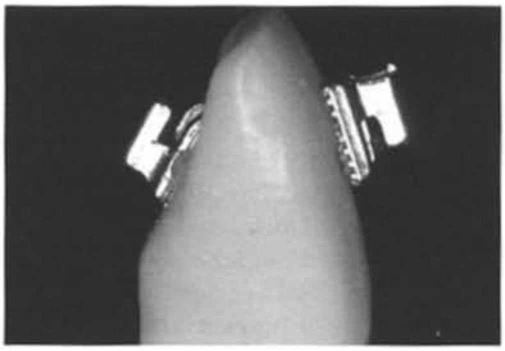


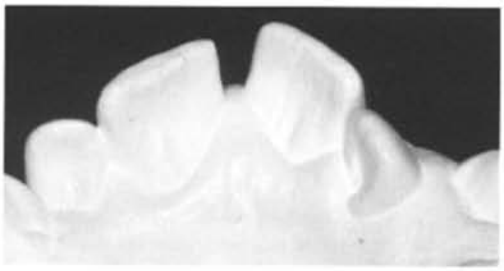
Fig. 1. The lingual ribbon arch bracket is positioned with the vertical slot directed towards the occlusal surface.

The Lingual Task Force members and others provided many reports on the continuing development of the lingual appliance (Scholz 1982, Gorman 1983, Alexander 1983, Kurz 1983, Smith 1983, Kelly 1982, Smith 1986, Artun 1987 and Greekmore 1989). In Australia there has been limited acceptance of lingual orthodontics by orthodontists. However, patients who have been offered the lingual orthodontic option are very enthusiastic in their acceptance (McCrostie 1995).

PATIENT SELECTION

The use of the lingual appliance is restricted almost entirely to adults. In adolescent patients the shorter clinical crown height often contraindicates its use (Fig 2A & B). Unless there is a specific request by the patient for lingual appliances, the adult patient should be treated by a conventional labial approach. To that extent patients select themselves to undertake treatment with lingual appliances. However, a large tongue that could be irritated by the appliance, the effect on speech initially and the level of gingival care and health are factors that may discourage a patient from proceeding. Lingual appliances may create some difficulty in speech for some patients but this improves within a few days.

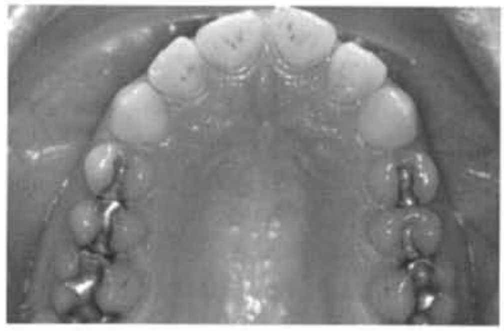
It is critically important that oral hygiene is maintained to a high standard both prior to bonding the attachments and throughout treatment. Gingival inflammation and hypertrophy, apart from causing patient discomfort, can be detrimental to appliance management in several ways (Fig 3A & B). These include difficulty of inserting lock pins without damaging the gingiva, when brackets require rebonding and with placement of stage III auxiliaries. Other considerations which pertain to adults include the presence of bridgework or crowns, devitalised teeth and the loss of investing bone.



A

B

Fig. 2. A & B - The shorter clinical crowns of most adolescent patients is a contra indication to the use of lingual appliances.



A

B

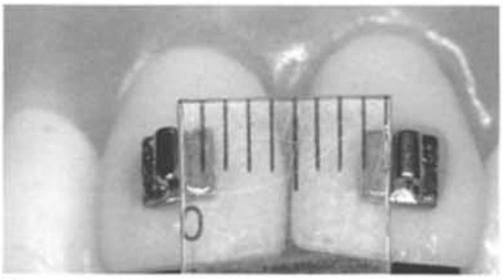
Fig. 3. A & B - Gingival hyperplasia can complicate appliance management. Note - palatal gingivae at commencement of lingual treatment compared to gingival hyperplasia present during stage 3 mechanics.

The orthodontists must determine whether their experience with lingual appliances allows them to treat that patient's malocclusion without compromise of standards. It would be prudent to select relatively simple cases initially, and have an agreement with these patients that labial appliances will be substituted should insurmountable problems arise. It is helpful when starting to use lingual appliances if patients are available for adjustments when adequate time can be allocated.

Fig. 4. Variable lingual tooth anatomy complicates placement of lingual attachments.

ANATOMICAL CONSIDERATIONS

There is much greater variation of contour of lingual tooth surfaces compared with their labial equivalents, for example marginal ridges of incisors, cinguli of lateral incisors and cuspids and accentuated or additional cusps of molars have to be taken into account (Fig 4). The buccolingual dimension of bicuspids and molars compared with the labio-palatal width of incisors and cuspids, and the variable occluso-gingival height of teeth, particularly of bicuspids, can modify appliance placement or archwire shape. In addition, interbracket measurements are significantly smaller where the appliance is placed lingually (Fig 5). Archwires need to be precisely measured and shaped to avoid undesirable space opening in the labial segments or expansion in the buccal segments. Problems may be encountered treating patients with short clinical crowns or those which have been subjected to heavy attrition, and teeth which are severely rotated or badly displaced. If the patient is made aware of some clinical difficulty, for example, the presence of a severely rotated tooth, or an open bite, he or she may be prepared to display a labial or buccal attachment to assist in the correction (Fig 6A & B). Time spent informing the patient of such problems and in detailing the operator's expectation of the outcome of treatment may avoid misunderstandings at the completion of treatment and of course this is valid for any form of treatment.



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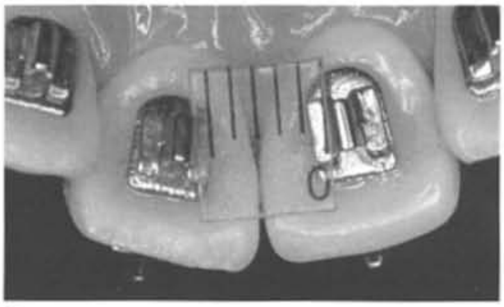


B

Fig. 5. Interbracket distances are significantly smaller when the appliance is placed lingually.

A - Labial ribbon arch bracket inter bracket distance = 9mm.

B - Lingual ribbon arch bracket inter bracket distance = 6mm.

A

B

Fig. 6. A - mid treatment.

B - post treatment.

Plastic buttons on the labial surfaces of teeth may be acceptable to the patient in circumstances where they greatly assist lingual appliance management. In this case closing the open bite was efficiently completed with vertical elastics worn whenever the patient was not in direct social contact.

MODIFICATION OF LABIAL APPLIANCE

Various systems can be employed lingually just as they are used labially and each has its benefits and its weaknesses. The choice will be made largely on the training and the competence of the particular orthodontist. The Begg Appliance, based on the use of ribbon arch brackets and round archwires, provides a relatively simple conversion from labial to lingual mechanics (Fig 7). In bracket placement the main change is that the bracket is turned upside down for lingual mechanics. Unlike the edgewise mechanism, bracket placement is simplified because torque is not built into the bracket. This removes the need to involve the services of commercial laboratories to place preangulated brackets on the model prior to indirect bonding. There is also less difficulty with subsequent rebonding of individual brackets if this becomes necessary. It is possible to use standard labial bracket bases on the lingual (Kesling 1983). However, the Begg ribbon arch bracket is available on specially designed lingually contoured bases (T.P. Orthodontics).

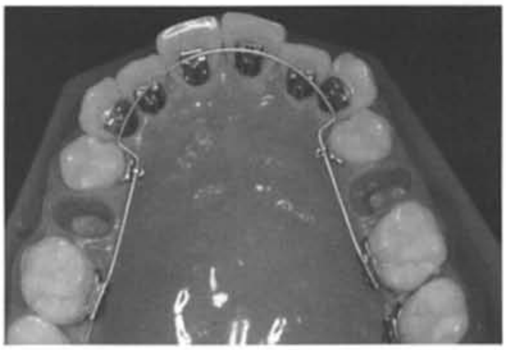
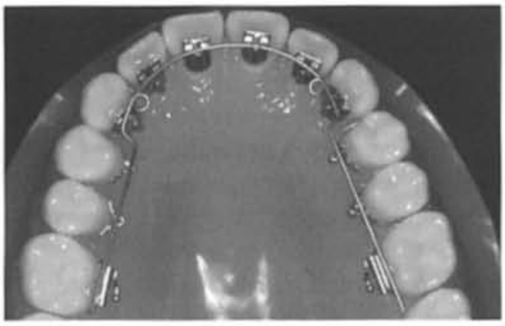


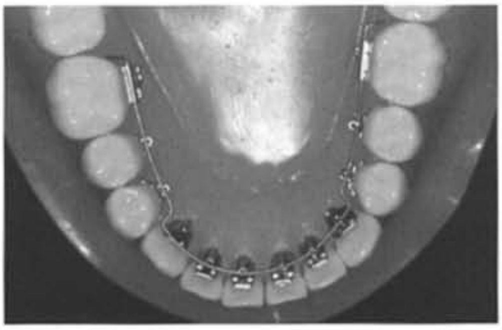
Fig. 7. The Begg appliance with its ribbon arch bracket and round arch wires provided a simple conversion from labial to lingual mechanics.

Arch wires for lingually placed brackets require modifications to accommodate the lingual anatomy of incisors, canines, bicuspids and molars (Fig 8A, B, C & D).

DIRECT BONDING

Direct bonding of lingual attachments is not recommended because of the great difficulty of judging bracket heights and mesio-distal positions. However, reasonable results may be obtained by preplanning bracket positions using a model in much the same way as is done in the indirect procedure.


A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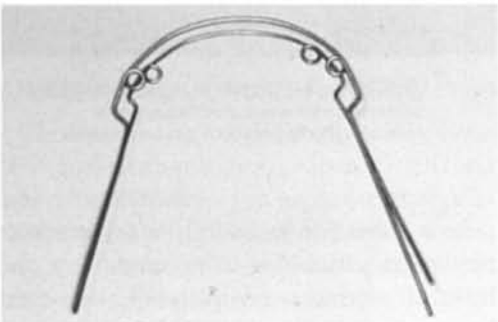

C


D

Fig. 8. Lingually placed archwires require offsets to accommodate the lingual anatomy of anterior and posterior teeth.

A - upper lingual arch wire.

B - lower lingual arch wire.

C - upper and lower lingual arch wires.

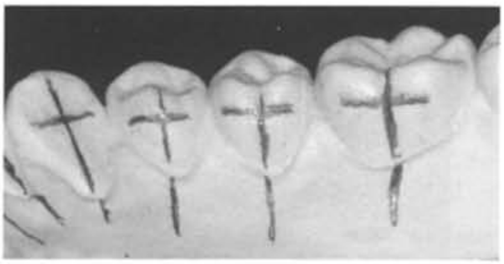
D - upper lingual arch with toe out for molar alignment.

INDIRECT BONDING

The use of indirect bonding is such an important part of a successful lingual treatment that a detailed description of one method is presented.

There are many different methods used to bond attachments indirectly (Segolz 1982, Zachrisson 1978, Zachrisson 1994, Thomas 1979 and Aquirre 1984). For example some methods may differ in the material used for the transfer tray. Other methods make use of light cure composite resin. Common to all methods is the need to perform each step in the procedure to a high standard. Indirect bonding is accurate and reliable (Artun 1987). When using the ribbon arch brackets, the laboratory preparation for bonding indirectly can be carried out in the orthodontic office. The following approach is suggested.


A



B

Fig. 9. A - Work model. The long axis is marked on each lingual tooth surface.

B - Starting with the bicuspids, the occlusal margin of each bracket is marked.

LABORATORY STAGES

1. A work model free from artefacts is prepared from an accurate alginate impression.
2. A line is drawn on the lingual surface of each tooth to indicate its long axis (Fig 9A).
3. Mark the level of the occlusal margin of the bicuspid bracket on the work model (Fig 9B). The bicuspid has a smaller occluso-gingival height than other teeth. Once the bicuspid bracket is fitted to avoid occlusal interference, then all the other brackets can be correctly placed.
4. If the bases of brackets and tubes are large, they are modified and adapted to fit the contour of the lingual tooth surface. If slight over-correction of alignment is desired, the bracket bases can be modified by contouring or by welding a length of ligature wire to either the mesial or distal or by the addition of composite under the mesial or distal bracket surface.
5. The work model is painted with a water soluble separating medium applied uniformly to all surfaces of the dental arch and palate.
6. When the separating medium has dried, the brackets and molar tubes are attached to the work model by means of composite resin mixed in small quantities and applied to the bracket bases (Fig 10). Each bracket is positioned according to the guidelines previously drawn on the model, and excess paste is immediately removed with a fine pointed instrument.

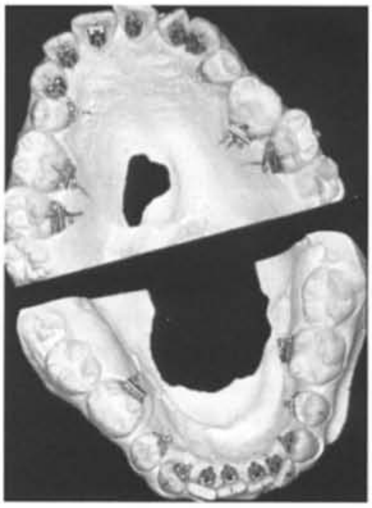
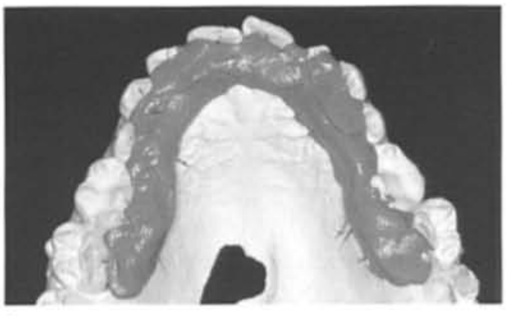


Fig. 10. The separating medium is painted on the model and the brackets are then bonded to the model.

7. A transfer tray is prepared from a material such as Express (3M Unitek Corporation). This material should be mixed according to the manufacturer's directions to ensure homogeneity. It is rolled into two lengths that extend from right molar to left molar. The first roll is pressed into the brackets and tubes (Fig 11A). The second roll is applied buccally and then pressed over the incisal and occlusal surfaces of the model (Fig 11B). It should be firmly but carefully adapted over the brackets and tubes on the palatal surfaces of the plaster teeth.

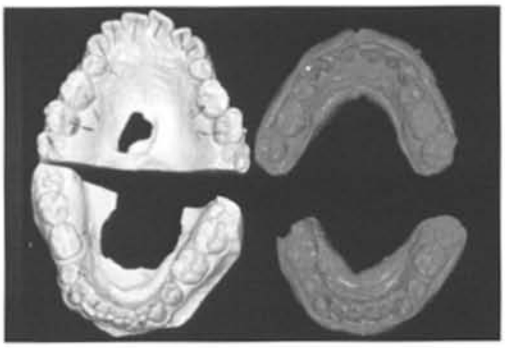
8. When it has set, excess material is removed reducing the height of the tray to the level of the gingival margin. The tray is extended one tooth distal to the most posterior bonded attachment to give adequate support. It is helpful to have marked the location of this attachment on the periphery of the model prior to making the tray so that in removing excess Express the end tube is not dislodged from the impression.
9. Immersion of the model in warm water for approximately twenty minutes dissolves the separating medium and allows the Express tray, with the attachments securely embedded, to be removed (Fig 11C). The margins of the tray can be further trimmed and a notch is cut labially to identify the midline of the dental arch to assist when seating the tray in the mouth.
10. Any contaminants are removed from the bracket bases with acetone or the surface may be micro etched (Fig. 11D).
11. The tray is then placed in a container such as a humidor to maintain its dimensional stability until required.
12. When difficulty of maintaining a dry field in a particular case is anticipated, for example with a large tongue, exaggerated swallowing action or limited mouth opening, the Express tray can be prepared and applied in sections.



A

B

C



D

Fig. 11. A - A roll of the material for the transfer tray is applied to the brackets and tubes to ensure good adaption.

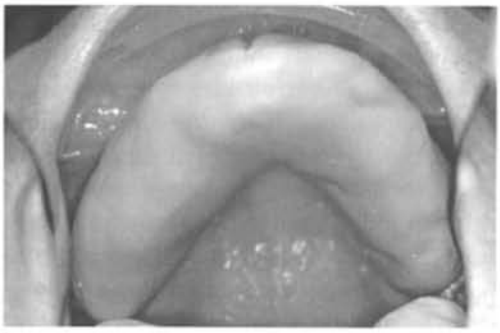
B - A second roll covers buccal, incisal and occlusal surfaces.

C - Models are immersed in water for 20 minutes.

D - Transfer tray with brackets removed from model.

CLINICAL STAGES

1. Preparation of teeth for indirect bonding is similar to that for direct bonding. They are thoroughly cleaned, dried and etched. A dry field must be maintained. If there is likelihood of moisture contamination from tongue movement or from saliva volume, suitable controls must be instituted or it may be necessary to carry out indirect bonding in quadrants rather than for whole arches.
2. The following method is used with a composite resin such as Concise (3M Unitek). The orthodontist applies liquid A to the prepared teeth surfaces, and the assistant uses liquid B on the bracket bases in the tray.
3. The Express tray is inserted into the patient's mouth, firmly seated and held stationary for approximately three minutes (Fig 12A). The space separating the bracket base from the tooth surface is determined by the thickness of the separating medium applied to the work model. The union of liquids A and B has to bridge this space. As the liquids are unfilled this union will be strong only if the void is not too wide, so the amount and thickness of the separating medium becomes crucial to the success of the bonding process.



A

B

Fig. 12. A - Transfer tray in the patient's mouth.
B. - Archwire inserted.

4. After five minutes the Express tray can be removed and any excess bonding material eliminated.
5. The next step is the direct bonding of any brackets omitted from the procedure, for example where gross crowding or overlapping of teeth would interfere with the insertion of the tray.
6. Remove any excess bonding material which would otherwise cause gingival irritation. The archwire can then be secured as soon as it is fabricated (Fig 12B).

INSTRUMENTS

A full range of purpose made lingual instruments may be purchased (Ormco, Unitek). For the lingual Begg Appliance it is possible to work with standard labial instruments aided by personal choice of one or two lingual instruments, the most popular being the Weingart style plier (Fig 13). For example, arch wire fabrication and cutting to size is done as for labial archwires. Insertion and removal of archwires is more difficult than with labial appliances. Access is improved by the use of lingual 139 pliers, Weingart pliers or similar pliers which facilitate lingual access because the beaks are curved or angled.

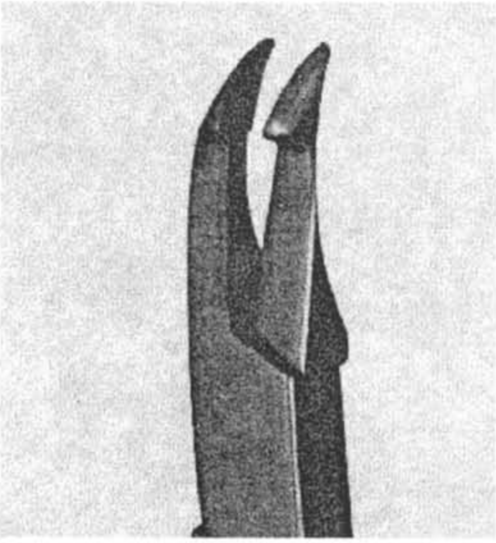


Fig. 13. The Weingart plier which is the best general purpose lingual instrument.

LOCKPINS

It is helpful to use softer and thinner lockpins for lingual Begg brackets. The lockpins of a thickness of 0.014 are recommended. This will aid the insertion and removal of lockpins. The premolar lockpin is the most difficult to seat fully and secure. A simple method is to place the lockpin into the bracket using a plier or cutter and then to use two hand instruments. The head of the pin is seated with one instrument while the tail is bent over with the other. Ligature tuckers are useful for this procedure (Fig 14A & B).

A

B

Fig. 14. A - A simple method of placing the lock pin is to use two hand instruments such as ligature tuckers.

B - A Weingart plier can be used to seat the pin tightly.

BRACKET AND TUBES

The standard labial ribbon arch (Begg) brackets and tubes are available on bonding bases small enough to use on the lingual surfaces (T.P. Orthodontics). Their attachments provide sufficient surface area of bracket base contact for adequate bonding strength. Low profile molar tubes reduce tongue irritation and lessen the need for molar offsets in the archwire.

BITE OPENING AND MANDIBULAR ROTATION

The presence of attachments on the lingual of the upper anterior teeth often creates an immediate interference preventing full mandibular closure (Gorman 1983, Smith 1986 and Fulmer 1989). There is a similarity to the interference created by labial appliances, for example, in a deep bite and minimal overjet situation (Jenner 1995). Management principles are the same for the lingual appliance as they are for the labial appliance. If the rotation of the mandible will not adversely affect the treatment mechanics, the treatment goals or the standard of the final result, the rotation can be ignored. This is true for most Class I and for many class 2 deep bite patients particularly if they tend to have low mandibular plane angles.

Mandibular rotation may adversely affect the treatment and treatment results for many patients with high mandibular plane angles. If the chin point is rotated down and back, then profile and appearance may be compromised to some extent. The occlusal relations will be more Class II immediately after lingual appliances are placed. Some borderline patients may require extractions as a consequence, others will require special focus on Class II mechanics to correct the increased severity of the class 2 relations.

LINGUAL MECHANICS

High pull headgear has been recommended for the high mandibular plane angle patients in order to provide a greater measure of vertical control (Smith 1986).

The Jasper Jumper, described by its inventor as an intra-oral headgear, provides a more cosmetic correction of vertical as well as anterio-posterior discrepancies (Cash 1991 and Blackwood 1991).

A posterior bite plate fitted at the time of lingual appliance insertion prevents molar eruptures and mandibular rotations and provides the patient with a convenient occlusal surface for mastication (Jenner 1995). The posterior bite plate uses occlusal forces to enhance anchorage by preventing molar movements vertically or horizontally (Fig 15). With the ribbon arch or Begg lingual appliance this enables immediate use of Class II elastics.

Cephalometric evaluation and comparison of treatment changes with labial and lingual appliances showed the two did not differ significantly (Gorman 1991). This suggests that lingual mechanics may be as successfully employed as labial mechanics in treating a large range of malocclusions.

A balance between elastic stimulation and archwire stiffness is required. The lightest Class II elastics may be combined with resilient 0.014 stainless steel arches (A.J. Wilcock) or preferably 0.016 stainless steel arches. The premium or premium plus grades are recommended.

If the Class II elastic force overbalances the archwire resistance then extrusion of incisors will occur (Kesling 1985).

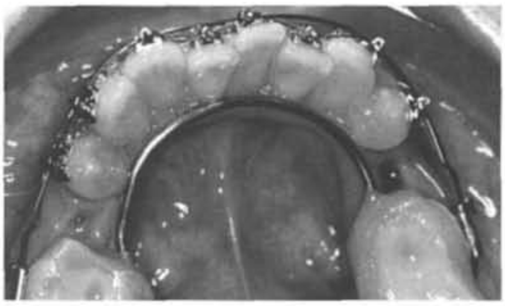


Fig. 15. A lower posterior bite plate fitted at the time of lingual appliance insertion prevents bracket interference between canines while providing a convenient occlusal surface for mastication.

ARCHWIRES

The selection of archwires in lingual treatment is similar to the selection in labial treatment. The initial archwires may be more flexible in order to compensate for the smaller interbracket distances. Thereafter, the diameter of the archwires should reflect the needs of the treatment stage, just as with labial appliances.

The lingual archwire has been described by Fujita (1979) as mushroom shaped with the segments distal to the cuspid much narrower than the anterior segment. It is important that the archform and width is maintained. A record of intermolar width is helpful, as is a photocopy or photograph of the archwire prior to insertion. These provide a useful reference for later in treatment.

Elastic hooks and elastics

Elastic hooks are bent into stainless steel archwires, usually mesial to the canine brackets. However, they may be placed distal

to the canine brackets if they complicate the insertion of tooth tipping springs. The hooks must be bent with the anterior segments nearest the palate and the buccal segments nearer the occlusal. In this way elastics can be most easily placed by the patient (Fig 16A, B & C). Hooks may be circular or oval in shape.

Bicuspid offsets

Bicuspid offset reflect the size and shape of the bicuspids relative to the canines.

Molar offsets

If low profile molar tubes are used, then no molar offset is required. If the molar tube has a high profile relative to the bicuspid bracket, then a molar offset is required.

Anchorage bends or anchorage curves

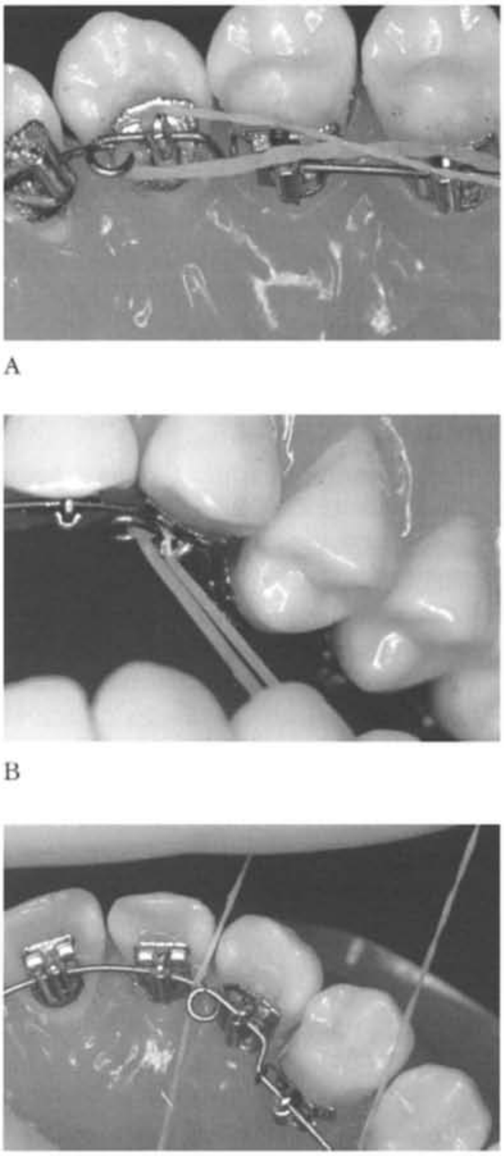
Anchorage bends or anchorage curves are placed mesial to the molar tubes and should reflect the need for bite opening and anchorage control.

Distal ends

Distal ends of the archwires should be annealed to allow easy bending once the archwires are in place. This is extremely important. Any distal end left protruding will cause great tongue irritation.

Coordination

Coordination and symmetry of archwires should be carefully checked as with labial appliances. Upper lingual and lower labial arch wires may be difficult to coordinate. The best approach is to begin with a standard lingual arch form, assess the treatment response and modify the arch forms by expansion or contraction as required. A copy of the archforms will be an invaluable reference by which future changes can be assessed (Fig. 17).



A

B

C

Fig. 16. Intermaxillary elastic hooks.

A - Intra-arch elastics.

B - Inter-arch elastics.

C - Engaging the elastic

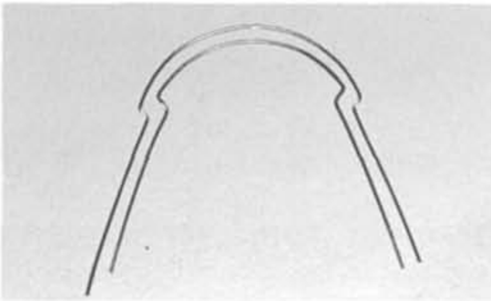


Fig. 17. Lingual arch forms have been described as having a key hole or mushroom shape.

Stage I Archwires

Where there is no crowding in an arch then lingual archwires may be the same diameter and grade as for labial archwires. The 0.016 stainless steel wire in premium grade or similar (A.J. Wilcock) has proved an excellent standard over many years. Where crowding or malalignment exists then the lingual archwires require more flexibility than corresponding labial archwires. Options available include:

- addition of vertical loops to the 0.016 archwire for added flexibility.
- smaller diameter archwires such as 0.012 or 0.014 for added flexibility.
- use of more flexible archwires of nickel/titanium such as are available in preformed lingual archforms or copper Niti labial arch forms (Ormco Corporation, Glendora, California). As soon as the anterior teeth are aligned, the thinner or more flexible arches are changed to thicker arches. By filling the bracket slot more completely, greater control over alignment will be achieved. Rotation springs may be applied in conjunction with thicker base arches for alignment of rotated teeth.

Intra-arch and inter-arch elastics should be avoided until adequate stiffness of archwires has been provided. For example, 0.014 stainless steel arches are likely to be overpowered even by light Class II elastics.

Stage II Archwires

The Stage I archwires may be adequate in Stage 2. However, greater arch form control, vertical control and alignment control is exerted by thicker arches ranging from 0.018 to 0.020 inch diameter stainless steel premium or similar grades (A.J. Wilcock).

Stage III Archwires and Auxiliaries

The 0.018 stage 2 arch or a new 0.020 arch will provide the base arch for the application of torquing auxiliaries and uprighting springs as with the labial Begg appliance.

Lingual root torque of upper incisors

Lingual root torque of upper incisors can be applied by loops located on the outer rather than the inner curves of the auxiliary wire (Fig. 18A, B & C). These spurs press on the incisal aspect of the lingual crown surface. The recomended wire is 0.012 stainless steel premium or similar (A.J. Wilcock), extended from molar tube to molar tube, or finished distal to the canines as convenience dictates. Placement of torquing auxiliaries is simplified if the active components are pinned into place last.

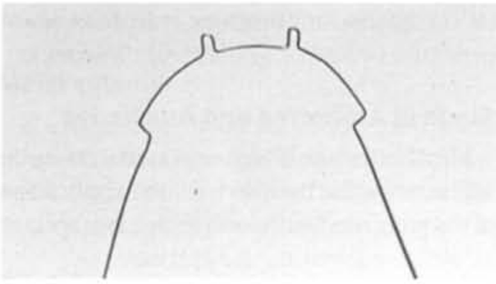
Labial root torque of upper lateral incisors

Labial root torque spurs are bent on the outer curve of a separate auxiliary but applied gingival to the lingual placed archwire (Fig. 18D, E & F). Alternatively, the ends of the auxiliary to torque the upper

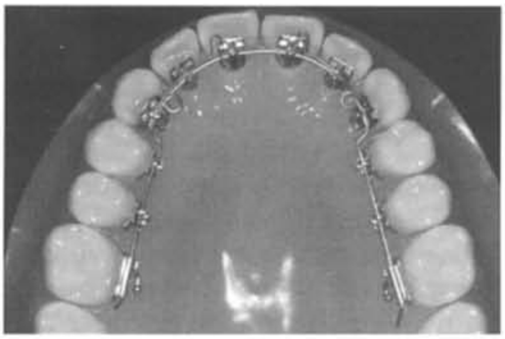
central incisor roots lingually can be returned gingival to the main archwire for this purpose.

Lingual root torque of the canines

Lingual root torque of the canines can be achieved with spurs on the outer curve of a separate auxiliary but applied incisal to the lingual archwire (Fig 18G, H & I).



A



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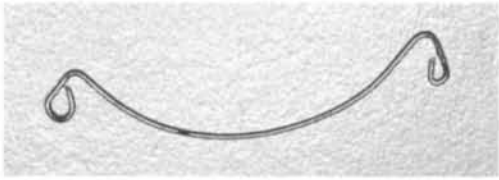

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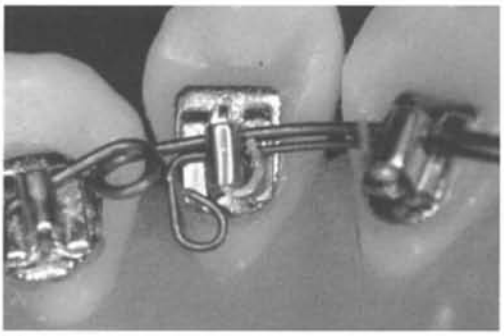
E



F

G

H

I

Fig. 18. Stage 3 auxiliaries - Labio lingual torque and Reverse Torque.

A - Lingual root torque to the 11 & 21 applied by a two spur auxiliary of 0.012 premium stainless steel (A.J.Wilcock).

B - Lingual root torque is applied by the spurs on the outer curve of the auxiliary acting on the incisal of the crown.

C - Auxiliaries are less cluttered if they have bicuspid offsets matching the main archwire.

D - Labial root torque to the 12 & 22 is applied by a short auxiliary of 0.012 premium stainless steel (A. J. Wilcock) with active spurs at the distal of the auxiliary.

E - The labial root torque is applied by spurs on the outer curve acting gingivally to the main archwire.

F - The gingivally directed spur will move the root labially.

G - Lingual root torque to the 13 & 23 is applied by a short auxiliary of 0.012 premium stainless steel (A. J. Wilcock) with active spurs at the distal ends.

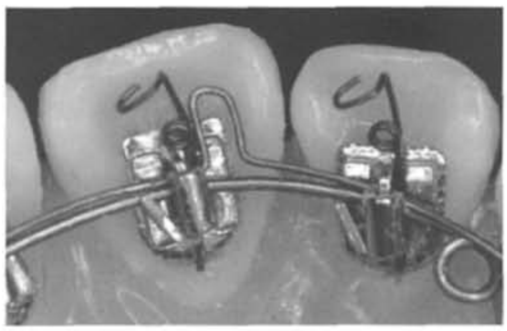
H - The auxiliary is inserted incisal to the main archwire.

I - The active torque spurs move the incisal aspect of the crown labially and thus the root is moved lingually.

Uprighting Springs

Mesio distal uprighting of teeth is often confined to the third stage of treatment. However, uprighting springs may be placed earlier than stage 3 to prevent tooth tipping and provide braking mechanics. Conventional uprighting springs, if they are large in size, are best placed from the gingival to avoid occlusal forces. The archwire should be held in place with a ligature wire. The ends of the springs may be annealed to more easily tuck them away from the tongue.

Mini-springs (Fig. 19A & B) of 0.010, (*A.J. Wilcock) may be placed from the occlusal side because of their small size. The mini-spring is better supported with a lockpin in place rather than a ligature. It can be attached with its hook to the outside or inside of the archwire as space dictates: simply select a left or right spring as required.



A

B

Fig. 19. Stage 3 auxiliaries - mesio distal uprighting.

A - mini spring insertion.

B - mini spring engaged.

Elastomerics

Elastic ligatures or chains may be used to hold spaces closed during torquing or uprighting.

Labial and Buccal Attachments to Supplement the Lingual Appliance

Just as in the labial appliance, a button or hook may be bonded to the opposite surface to facilitate rotational correction. Where aesthetics may be affected, a plastic attachment is preferred.

Molar tubes and premolar brackets can be placed buccally for alignment of second molars where this is more convenient.

Finishing

In its simplest form, finishing will involve reshaping of stage 3 archwires, removing torquing and uprighting auxiliaries, adding bayonet bends, and where necessary rebonding attachments to improve crown heights and tooth rotations (Fig. 20A & B).

Finishing may be extended by the use of a positioner or a retainer designed for minor tooth movements.

Retention

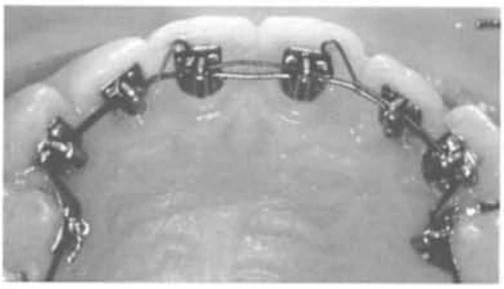
Any retainer suitable for labial orthodontic treatment will also be effective for lingual treatment.

The more aesthetic suck down retainers are more likely to be worn.

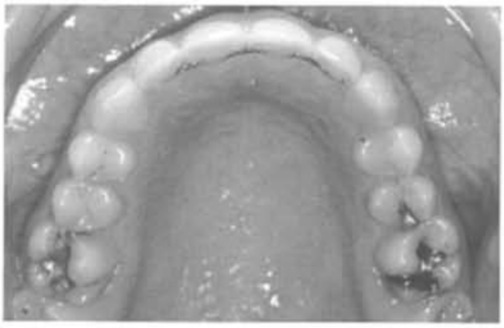
The ideal retainer is the bonded lingual retainer (Fig. 20C) which is out of sight, does not rely on patient cooperation and can provide 100% effective retention for as long as it remains in place. Twist wire of adequate stiffness is fitted to the lingual surfaces of the upper and lower anterior teeth. The end of treatment models facilitate their fabrication chairside or in the laboratory. The upper bonded wire is restricted to the upper incisors. If the canines were rotated, then the extra difficulty of fabricating the longer wires to the canines is justified. The upper wire must avoid incisal contact. The use of a light cure bonding technique is recommended to ensure adequate bond strength and excellent contour of the bonds. The contour of the bonds is important in maintaining good gingival health with brushing and flossing.

A conventional retainer is constructed to supplement the bonded upper retainer and to control the buccal segments.

A



B



C

Fig. 20. Bonded lingual retainers.
A - Pre treatment.
B - Stage 3 lingual appliance.
C - Bonded lingual retainer 6 years post treatment.

Scheduling Lingual Treatment

When lingual treatment is first introduced into a practice, much more time should be allocated than is thought necessary. For example, with archwire reshaping and new archwire fabrication allow double the time required for labial appliances. As competency improves the time can be reduced. In this way the patient's treatment does not suffer and the orthodontist and staff do not become distressed by unexpectedly longer apointments.

Scheduling lingual patients during non-busy periods of the day is recommended for the same reasons.

Conclusion

The lingual orthodontic appliance provides an important alternative to the patient who has refused conventional orthodontic treatment. Other patients who perhaps would have tolerated labial appliances are particularly pleased to accept lingual appliances and avoid any social disruptions to their lives.

The ribbon arch or Begg bracket is particularly suitable for lingual appliance treatment. What is lacking in sophistication is more than compensated for by simplicity of application and adaptability to the successful treatment of mild, moderate and severe malocclusions.

CASE REPORT

Patient: SD *Age:* 21 years 1 month *Sex:* Female *Treatment Duration:* 2 years 1 month

Appliances Used: Upper lingual ribbon arch brackets. Lower labial ceramic and plastic ribbon arch brackets

Chief Complaint: Prominent 13 & 23 with poor alignment of upper incisors. Request for lingual appliances so that there would be no disruption to her social life.

Diagnosis: Mild class 2 skeletal base. Full unit class 2 Dental discrepancy. Deep bite and retroclined upper incisors

Treatment Plan: Extraction of 15 & 25. Maintain the patient's good profile. Correct the alignment, deep bite and class 2 occlusion. Improve the axial inclination of the retroclined upper incisors. The lower arch to be maintained without extractions.

Treatment: Upper lingual indirect placement of ribbon arch brackets and lower labial direct placement of ceramic (Elipse) ribbon arch brackets.

Initial archwires of Nickel Titanium, (preformed upper lingual), both 0.016 inch diameter. A lower plastic plate (Trutain) provided posterior contacts in eating and incisal protection at nights in case of bruxism. The plate was discontinued after 2 months as the posterior teeth established adequate occlusal contacts.

After three months steel arches with anchorage bends were placed and class 2 elastics commenced. The overjet was 7mm having increased with alignment.

After nine months lingual root torque was applied to the 11 & 21 using an 0.012 auxiliary, incisally activated. The class 2 elastics had reduced the overjet and this was a good time to apply the brakes while improving the upper incisor inclinations.

Distal root uprighting of 14 & 24 also added to the anterior braking while elastic thread was applied between upper molars and upper canines in completing space closure.

After 18 months, torque and root uprighting auxiliaries were removed and finishing commenced.

Retention: Bonded upper and lower lingual retainers were provided. An upper trutain included tooth movements to push the 13 slightly palatally.

The patient is really pleased and thinks her teeth are fantastic. Now she is looking forward to starting her new job as a flight attendant where she will put her smile to good use.

TREATMENT RECORDS

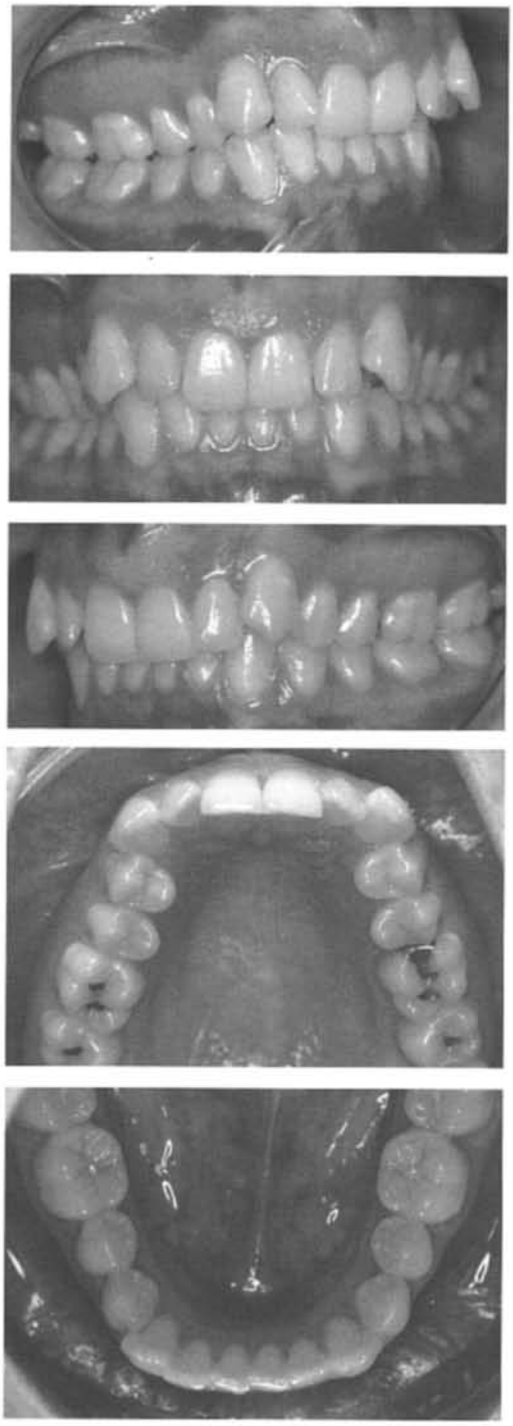


Fig. 22. Initial appliances after 6 weeks. Note lower occlusal splint to compensate for incisal and bracket interference. The overjet is starting to increase.

Fig. 21. Pre-treatment facial, intra oral and occlusal views.

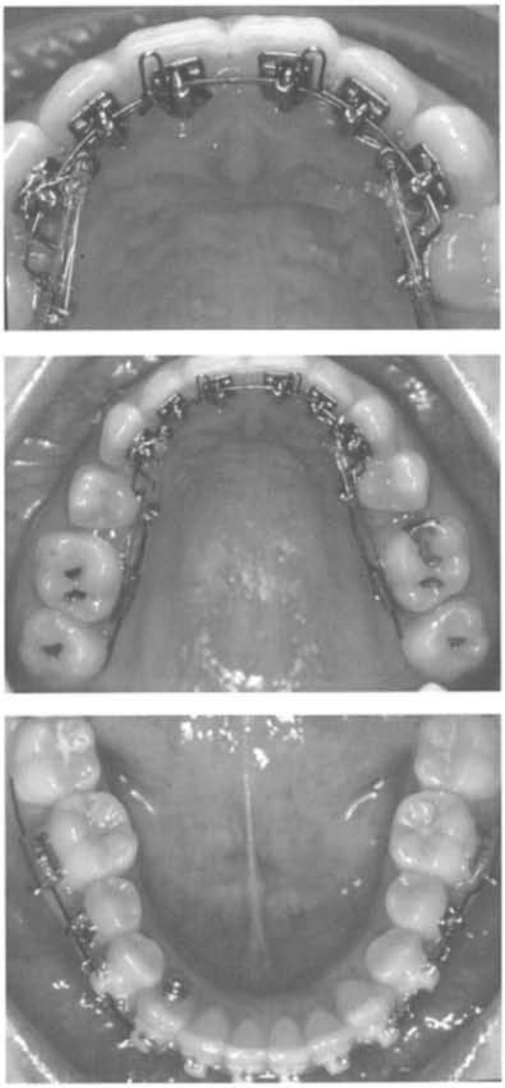


Fig. 23. After 9 months of treatment. Note retraction of upper canines and premolars. The incisor relation is good thus a torquing auxiliary is added to the 11 & 21 to act as a brake against further retraction while simultaneously improving the incisor inclinations.

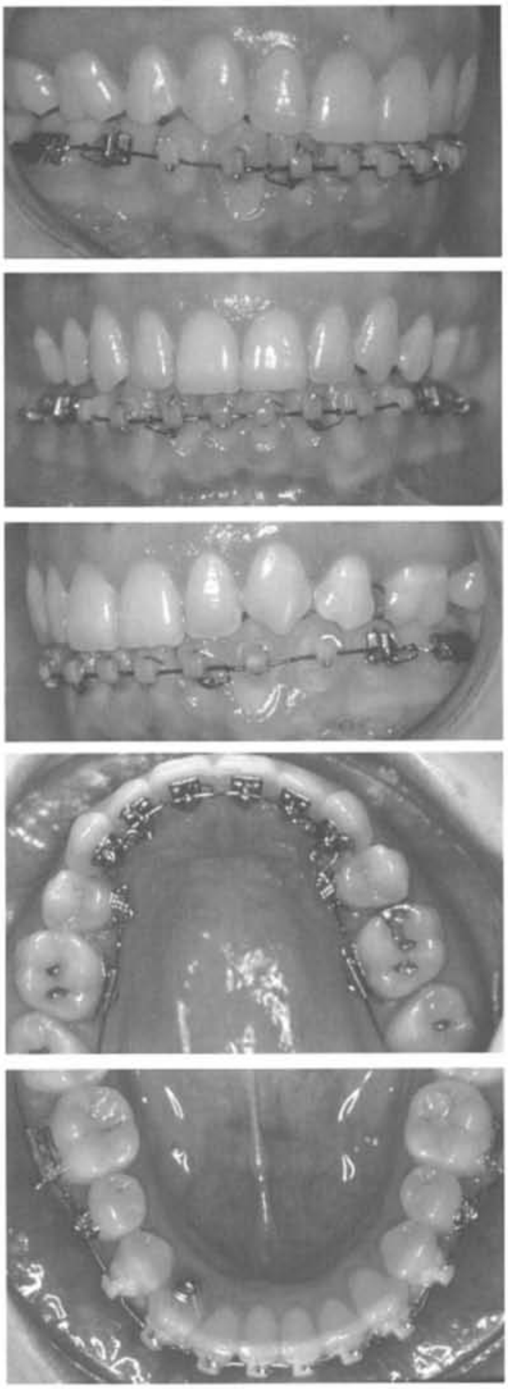
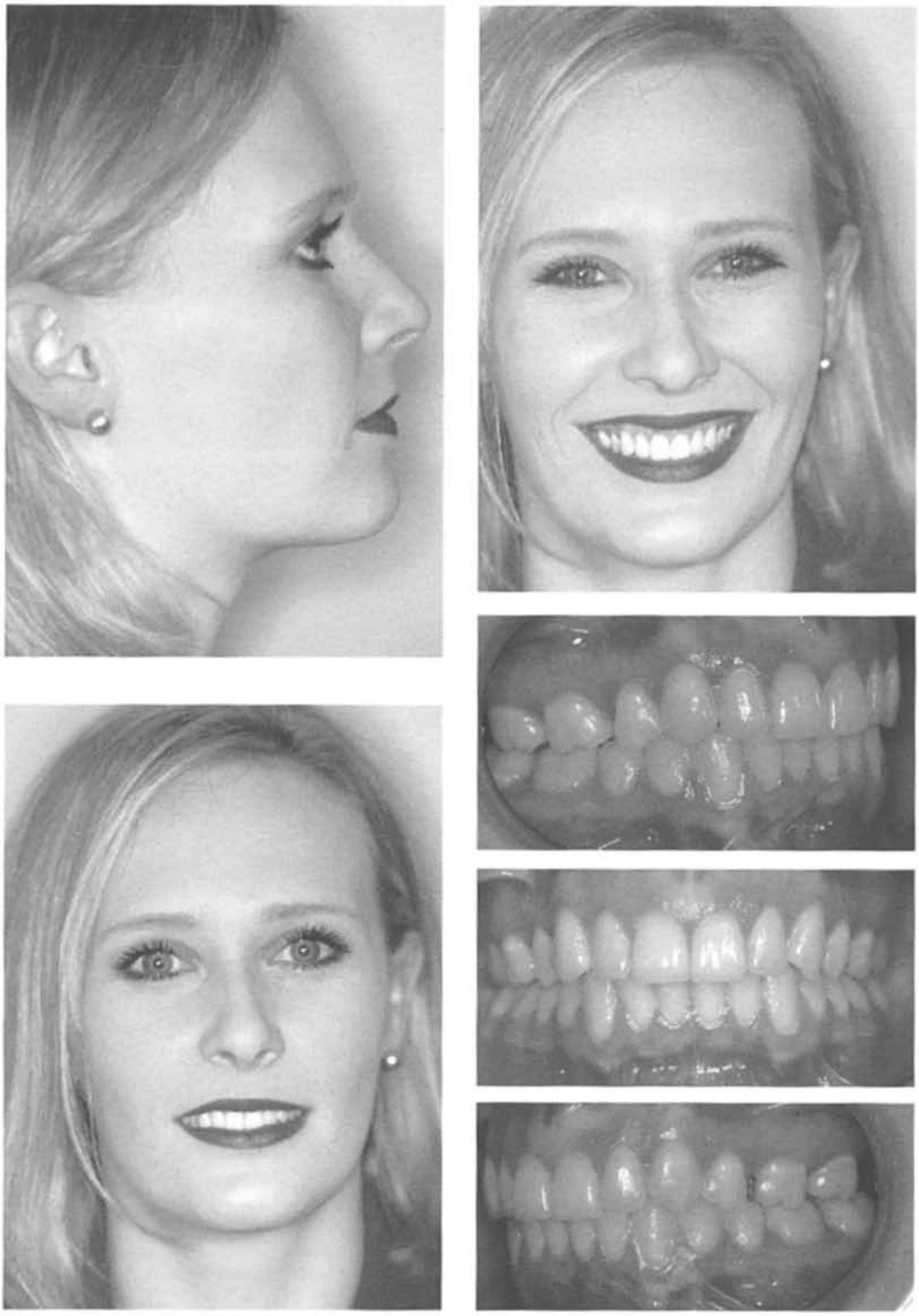


Fig. 24. After 20 months of treatment. Note distal root uprighting springs still acting on the 24 & 34. Torquing auxiliary removed from 11 & 21.



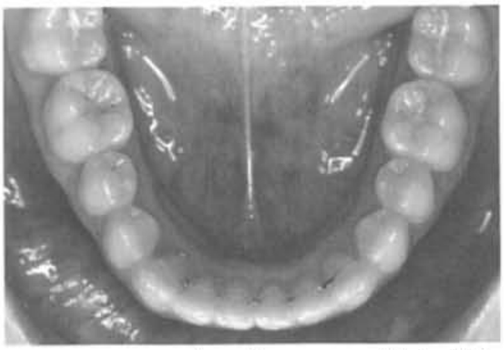


Fig. 25. After 25 months appliances removed. Note slightly labial position of 13.

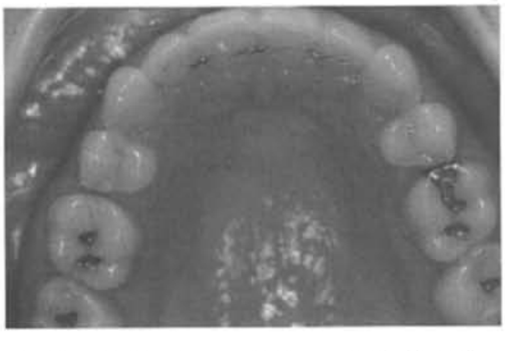
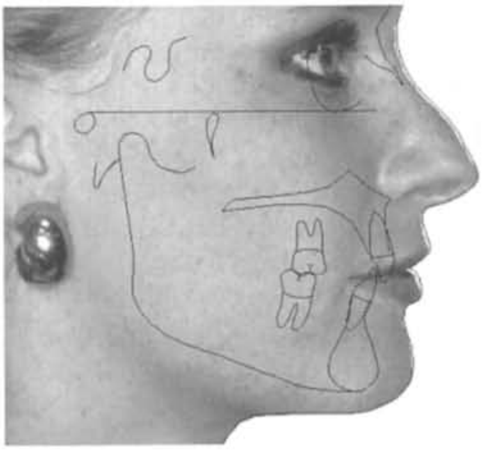
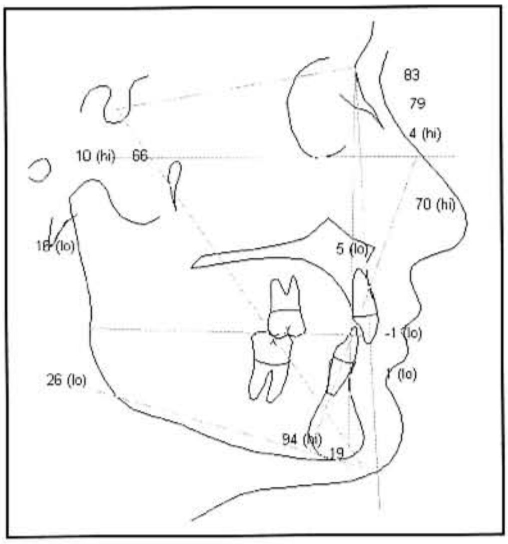
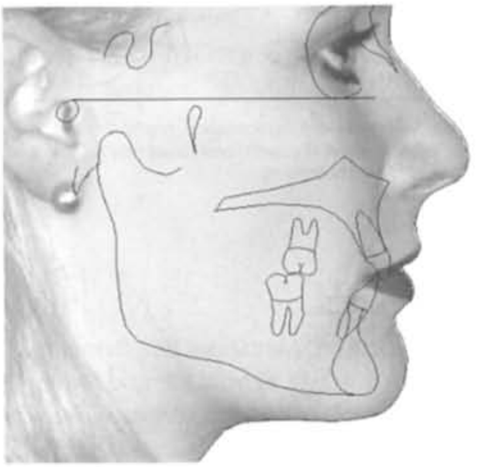


Fig. 26. After 26 months the 13 has improved with a splint retainer (Trutain) after resetting the tooth position on the work model.







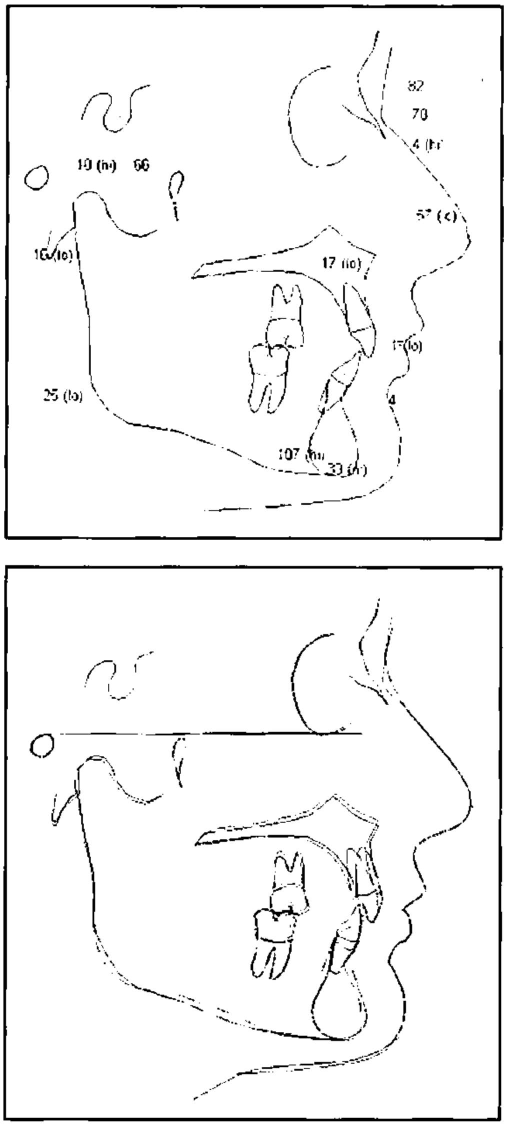


Fig. 27. Cephalometric Comparisons, pre-treatment, post treatment and superimposition of pre-treatment and post treatment.

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11
The Tip Edge Appliance

Colin C Twelftree

INTRODUCTION

The Tip Edge bracket was developed by Dr Peter Kesling to overcome the lack of control experienced by some orthodontists using the ribbon arch bracket in the Begg appliance. It was derived from a unique modification to the classical edgewise bracket and has a labially facing slot and traditional ligation with elastomerics (Fig. 1). Crown tipping is permitted in one direction only.

In Begg treatment, most teeth are initially tipped towards their final position and root angulation is subsequently corrected. Most teeth initially tip distally and this facility allows very light forces to depress anterior teeth to open deep bites. The Tip Edge bracket allows this distal tipping to occur but prescription crown tip and torque are also built into the bracket for final root positioning.

The archwire slot is 0.022" by 0.028" but as the tooth tips the vertical dimension of the slot increases to 0.028". This opening allows full sized archwires to be engaged early in treatment which maximises molar and vertical control.

Rotational control is provided by lateral extensions behind the archwire and these extensions remain in contact with the archwire even when the tooth is tipped. The bracket incorporates a vertical slot to accept auxiliaries for tooth alignment and root uprighting. The vertical slot is 0.020" by 0.020" square and accepts elastic or stainless steel ligatures to align severely malposed teeth.

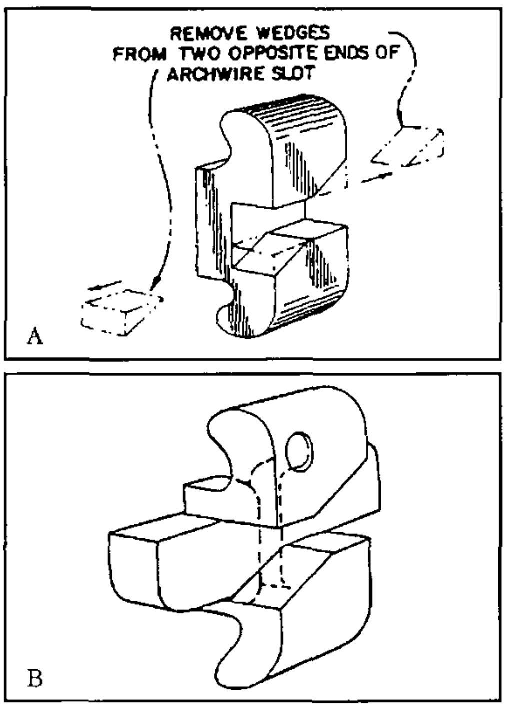


Fig. 1. A - Removal of diagonally opposed corners of a conventional edgewise archwire slot to create the basic tip-edge bracket.

B - Addition of rotation wings and a verticle slot enhances both rotational and tip control.

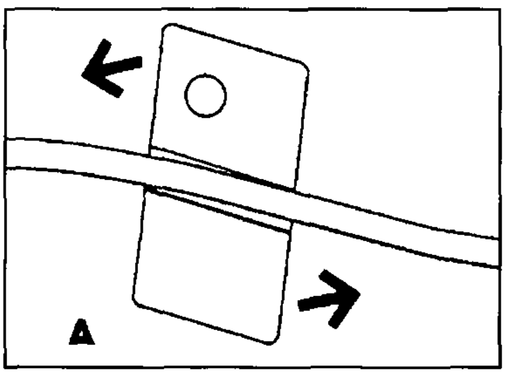
Advantages of Tip Edge brackets over ribbon arch brackets

Ribbon arch brackets appear old fashioned and the use of a lock pin is not favoured by orthodontists. Tipping in each direction permits magnificent anchorage control and overbite reduction but unwanted movements are difficult to control. The incorporation of a three dimensional prescription within the bracket is virtually impossible and complete derotation of the tooth is required before complete engagement is possible.

The Tip Edge bracket retains the advantages of initial tipping in desired directions while using a labially facing slot and elastomeric ligation. Unwanted movements are minimised.

Advantages of Tip Edge brackets

Traditional Edgewise brackets do not permit teeth to tip. Therefore, when archwires are initially engaged root movements are commenced immediately. This maximises friction between the archwire and bracket and restricts initial wires to small dimensions or materials of low elastic modulus. Undesirable couples created by these forces increase anchorage demands and increase the force on the muscle sling which reduces vertical control (Fig 2).



Tip Edge Archwire Slots

With the tooth at its desired angulation, the archwire slot is 0.022" by 0.028". However, if the tooth is tipped the archwire slot increases its vertical dimension. Therefore, initial 0.016" steel archwires are able to be engaged very early in treatment which allows the use of light elastics to correct anteroposterior discrepancies virtually immediately. A period of initial alignment which may worsen certain aspects of the malocclusion is generally not necessary.

As crowns are progressively tipped towards their final position, the archwire slot opens more permitting the engagement of a 0.022" round archwire early in treatment when Stage I requirements have been met. As these wires can be passively engaged, patient discomfort is minimised as is bond failure.

In Stage III, when the roots are tipped towards their final angulation, the slot closes down onto the full size wire. Thus, the full prescription of the bracket is brought into play to optimise the final position of the teeth.

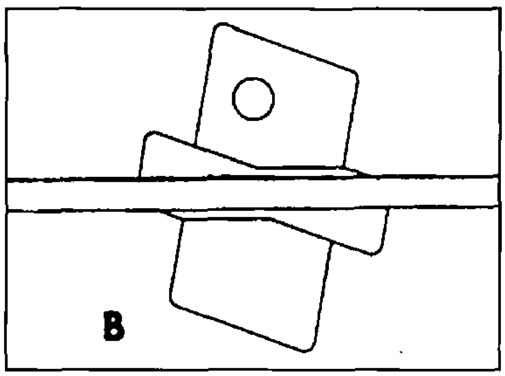


Fig. 2. A - Conventional edgewise bracket on upper anterior tooth tipped at start of treatment. Undesired couples and moments (arrows) are created which interfere with bite opening.

B - Tip-edge bracket on same tooth eliminates couples to permit desired bite opening from only 0.2 ounce (per tooth).

It is not necessary to vary the prescription of the bracket to overcome the necessity to use less than full size archwires.

The standard prescription for individual Tip Edge brackets is shown in Fig 3.

Fig. 3. Initial crown tipping and final crown tip and torque angles for tip-edge bracket archwire slots. Slot design is the same for each tooth in all types and classes of malocclusions. The only choice to be made is the direction of free crown tipping of premolars as shown.

Tip-edge bracket archwire slot angulations (Rx1)
(Slot size - .022")

	Initial, Mesiodistal Crown Tip	Final Crown Tip	Final Root Torque
Maxillary			
Central incisor	20° distal	5°	12°
Lateral incisor	20° distal	9°	8°
Cuspid	25° distal	11°	-4°
First premolar	20° distal or mesial	0°	-7°
Second premolar	20° distal or mesial	0°	-7°
Mandibular			
Central incisor	20° distal	2°	-1°
Lateral incisor	20° distal	5°	-1°
Cuspid	25° distal	5°	-11°
First premolar	20° distal or mesial	0°	-20°
Second premolar	20° distal or mesial	0°	-20°

Overcorrection

Traditional Begg mechanics encourages overcorrection to maximise the long term prognosis of the position of individual teeth. Overcorrections are easily accomplished with traditional ribbon arch brackets. Overcorrection in most dimensions is available with the Tip Edge bracket, especially if round wires are used in Stage III. Overcorrection of rotations is still accomplished by off-setting the bracket and overcorrection of final tip position must be built into the appliance when brackets are bonded. If rectangular wires are used in Stage III then overcorrection of torque values is difficult to achieve as is the case with standard Edgewise or Straightwire treatment.

Summary

The Tip Edge bracket incorporates the advantages of the ribbon arch bracket without the inherent disadvantages of that system. The advantages of the Edgewise system of good control are available with the Tip Edge system but the disadvantages of heavy force values and slow tooth movement are avoided. As light forces are used, anchorage and vertical control are maximised and headgear use is minimised.

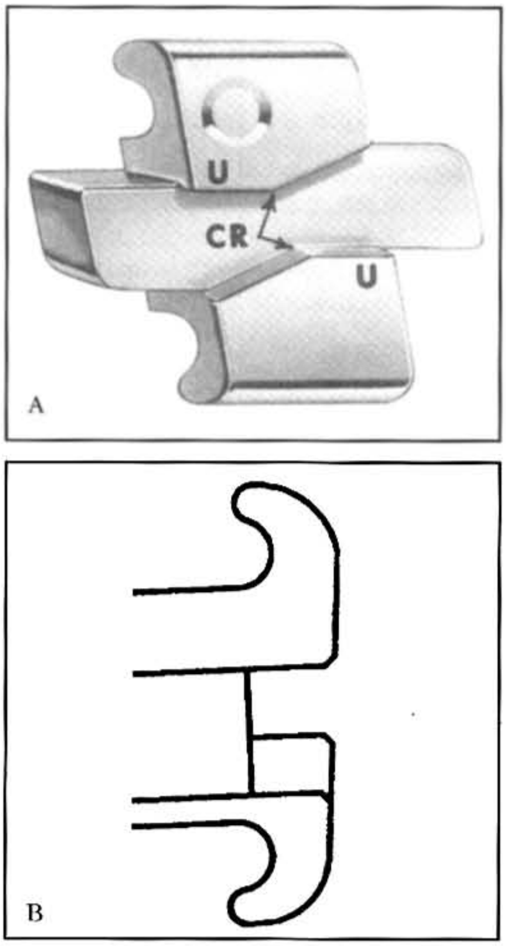
It is not necessary to extract teeth to provide anchorage for the correction of anteroposterior discrepancies. Extractions are required only for crowding relief and retraction of arches. The mechanics of treatment are essentially similar to the Begg appliance using the ribbon arch bracket.

As the use of the Begg appliance is covered elsewhere, it is not necessary to repeat details of the use of elastics and the various stages of treatment in this chapter unless there are any peculiarities related to differences between ribbon arch brackets and Tip Edge Brackets.

Appliances Tip-Edge Brackets

Tip Edge brackets, (Figure 4 A-C), are designed to permit distal crown tipping of all teeth except those distal to extraction spaces which tip mesially. Canines are free to tip 25 degrees and all other teeth 20 degrees. The uprighting surfaces (U) of the archwire slot determine the final tip angulation reached with an uprighting spring. These surfaces can also control torque if an edgewise archwire is engaged during uprighting. Archwires are retained in the slot with elastomeric rings.

Tip Edge brackets, in conjunction with .016" round archwires, allow the crowns of anterior teeth to tip distally and lingually under very light pressures. The elastic forces are so light (2 to 3 ounces on each side) the anchor molars remain relatively undisturbed. The one-point contacts between the central ridges of the slots and the archwire also permit the roots of the anterior teeth to seek their individual paths of least resistance under the light intrusive forces from the .016" archwires. If brackets with archwire slots that prevent mesiodistal tipping or archwires with rectangular cross-sections are used, the anterior teeth would not be able to react independently of each other. This could retard or even prevent anterior tooth retraction and/or depression and ultimately lead to prolonged treatment, a poor quality result or necessitate the use of extraoral force.



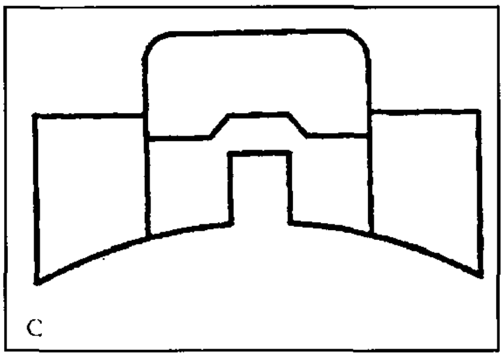


Fig. 4. A - Tip-edge bracket for upper right canine. Uprighting surfaces (U) can control final tip and torque angles for each tooth. Central ridges (CR) provide vertical control and also torque when a rectangular archwire is employed.

B - Distal view of upper right canine bracket. Low profile promotes comfort. Torque in archwire slot permits labiolingual root control with a rectangular archwire if desired.

C - Incisal view of upper canine bracket. Verticle slot accepts many auxiliaries. Lateral extensions provide rotational control permitting narrow bracket body width.

Tip Edge archwire slots are designed to permit initial, mesiodistal crown tipping. This prevents "bowing" of the archwire during retraction and / or space closure and automatically enhances anchorage when required. Illustrations below should be carefully studied while considering the desired direction of crown tipping required in each situation, (Figures 5,6 &7).

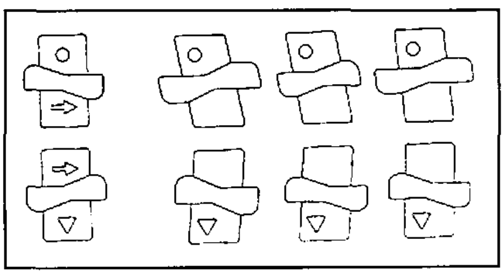


Fig. 5. Tip-edge brackets with archwire slots designed to permit crown tipping required for treatment of a first premolar extraction case.

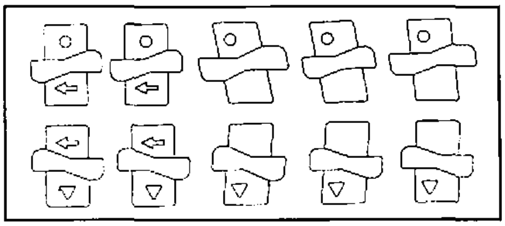


Fig. 6. Tip-edge brackets with archwire slots for a nonextraction or first molar extraction case.

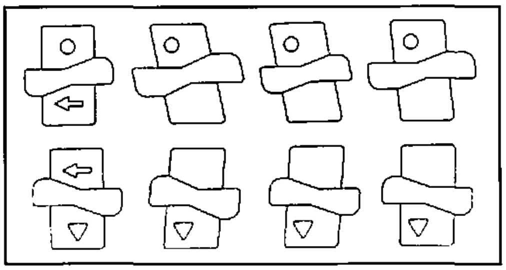


Fig. 7. Tip-edge brackets as required for a second premolar extraction case.

Universal Premolar Tip-Edge Brackets

By accepting similar torque and tip angles for first and second premolars: Upper 0 tip, -7 torque, Lower 0 tip and -20 torque, it is possible to reduce bracket inventories and have just two upper and two lower bicuspid brackets. These brackets can then be switched from right to left (not from upper to lower) to provide clockwise or anticlockwise crown tipping according to the need of each case (Fig. 8).

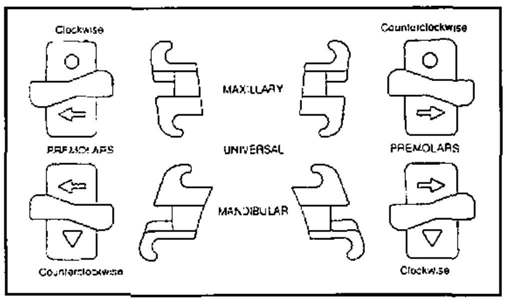


Fig. 8. Universal premolar tip-edge brackets arrows on the occlusal wings indicate the directions of crown tipping. Circle indents designate maxillary brackets, triangles mandibular brackets.

Universal premolar Tip Edge brackets are placed with arrows pointing in the direction of initial crown tipping desired. Normally, arrows point distally on premolars except when a first premolar has been extracted. In such a case the arrow on the second premolar should point mesially, as in the lower arch (Fig 9).

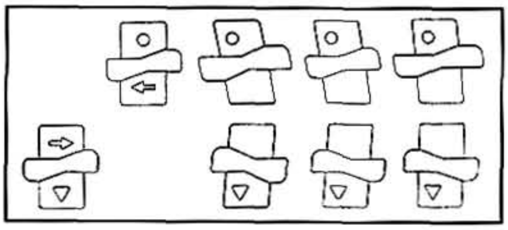
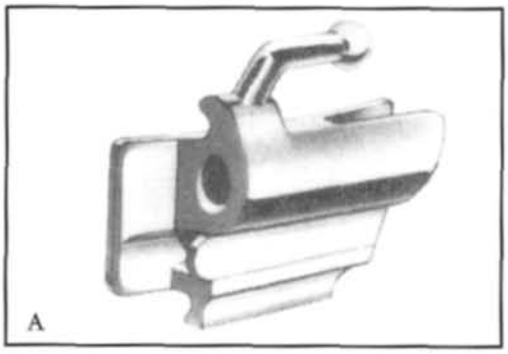
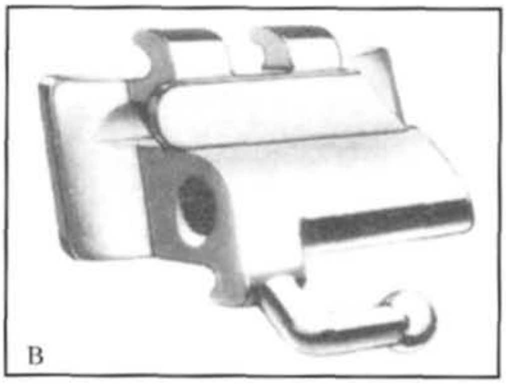


Fig. 9. Proper placement of universal premolar brackets on a case with pretreatment extraction of the upper second premolar and the lower first premolar.

Molar Tubes

Molar attachments for differential tooth movement are designed to keep the molars upright yet permit free sliding of the archwire. This is necessary to facilitate retraction of anterior teeth from light (2 ounce) forces. Tip Edge molar tubes are cast and have a .036" round gingival tube and a .022" X .028" occlusal tube with a removable cap (Fig 10A ,B & C). The extra length of the gingival tube reduces friction from a strong anchor bend in the archwire and increases rotational control. Slant-back design facilitates the straightening of the ends of archwires for removal.





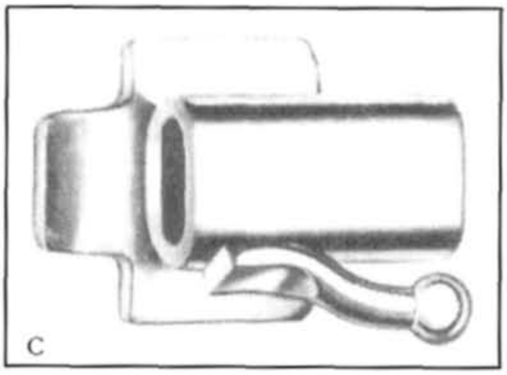


Fig. 10. A - Tip-edge tube for the maxillary left molar

B - Tip-edge tube for the mandibular left molar.

C - Flat-oval buccal tube for mandibular left molar - normally required only when first molars are missing and are replaced by a tip-edge tube during stage II.

Tubes are placed so that the rectangular, occlusal tube is at the same level as the archwire slots in the premolar brackets. This permits the subsequent placement of a straight archwire through the brackets and tube after the bite has been opened (Fig. 11).

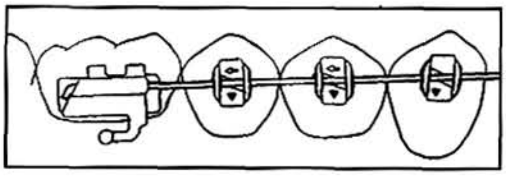


Fig. 11.

The use of flat oval molar tubes is indicated when there is no tooth mesial to the anchor molar or when the anchor molar is severely tipped buccolingually and extra torque control is required. This is the situation when first permanent molars or second premolars have been extracted. When the extraction space is closed and the anchor molars are in their desired positions, the oval tube can be discarded and a normal rectangular tube utilised. Combination tubes are available for this purpose. The oval buccal tubes accept a doubled back 0.016" steel archwire which provides good three dimensional control for the anchorage tooth while permitting bite opening forces to the incisors.

In/Out Compensation

Tip Edge brackets are cast with in/out compensation to eliminate the need for lateral, bicuspid or molar offsets. Each bracket has a vertical slot to accept positioning jigs, rotating springs, power pins or side-winder springs as required (Fig.12).

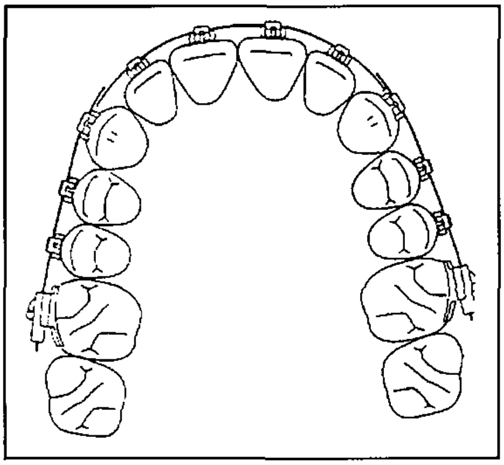


Fig. 12.

Placement of Tip-Edge Attachments

Tip Edge brackets with labially facing archwire slots must be accurately placed on teeth. This is necessary not only for smooth differential tooth movement through Stage I, II and III, but also to provide final, precise tooth positioning from plain rectangular archwires, if desired.

Positioning jigs ensure proper archwire levels in relation to incisal edges and cusp tips. Suggested heights and corresponding jig colours are shown in Figure 13. An additional 5mm jig (green) is available if desired.

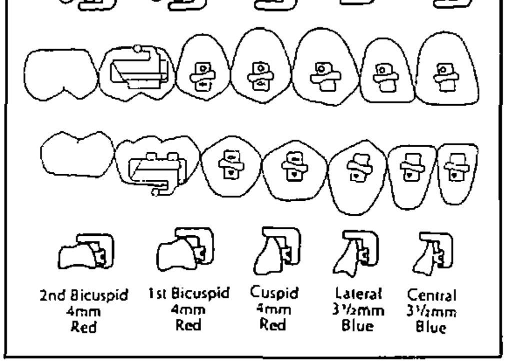


Fig. 13. Tip-edge brackets bonded with sides parallel to long axes of crowns. Bracket heights can be accurately controlled by using positioning jigs.

Alternatively, mid-crown bracket positions as described by Dr L F Andrews may be used, especially when anchorage demands are slight.

Usually the distance from the archwire slots to the incisal edges or cusp tips is 4mm. If the distance is less, the chances for occlusal interferences and/or bracket displacement increase. If this distance increases and the brackets are placed further gingivally, there will be less room for torque spurs and other auxiliaries. Of even greater importance, it will be difficult to maintain dental arch length and

rotation control because the archwire will be below the contact points between the teeth. The archwire slot in the upper lateral incisor bracket is usually placed 31/2mm from the incisal edge, except when this tooth is originally displaced lingually. In that case, it is placed 4mm from the mesial edge.

Jigs for premolars may have the tips of their occlusal arms bent in the direction of desired crown tipping, i.e. mesially for use on second premolars when the first premolars have been extracted and distally for all other situations (Fig. 14). Arrows cast into the faces of all premolar brackets also indicate directions of crown tipping.

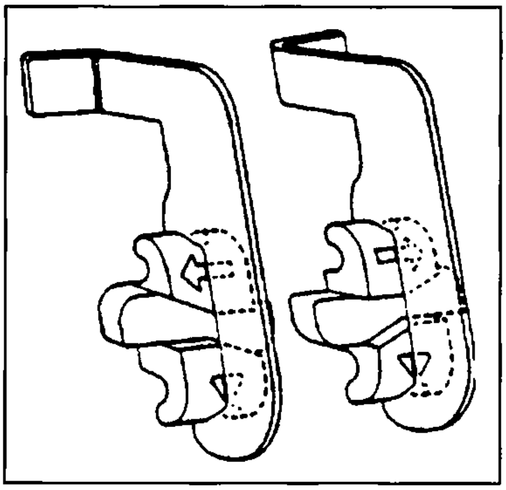


Fig. 14.

Molar tubes are placed parallel with the occlusal surfaces of the anchor molars. The .036" round tubes are always positioned gingivally to help prevent the archwire from being distorted from occlusal forces. The rectangular tubes are placed at the same levels as the bicuspid archwire slots, eliminating any need for vertical offsets in the .022" round or rectangular archwires.

Of course, the archwire slots in Tip Edge brackets are designed not only to provide the final degrees of tip and torque desired for each tooth but also to permit crowns to tip distally - except those distal to extraction sites, which tip mesially(Fig. 15).

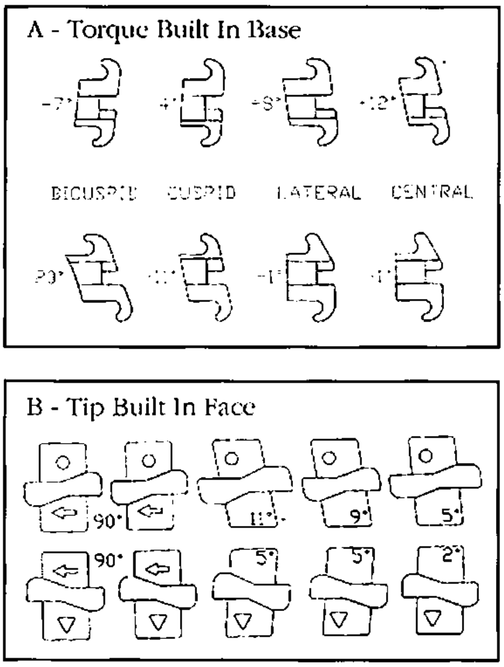


Fig. 15. A - Torque in the base of Rx-1 tip-edge brackets is appropriate for finishing of Class I apical base malocclusions with rectangular archwires.

B - Tip angles built into the face (archwire slots) of Rx-1 brackets automatically provide proper inclinations. Continued use of side-winder springs in conjunction with less than .022" archwires can provide "over uprighting" if desired. Note 5° tip on lower lateral incisor to help promote posttreatment stability.

Brackets should be placed in the centre of the labial or buccal surfaces of crowns for ideal alignment (Fig 16). Overrotations of flat surfaced anterior teeth are effected and / or held through bayonet bends in the archwire.

Brackets are bonded off centre on rotated cuspids and bicuspids to hold them overrotated throughout treatment (Fig 17). Rotation is accomplished by a rotating spring or an elastomeric tie.

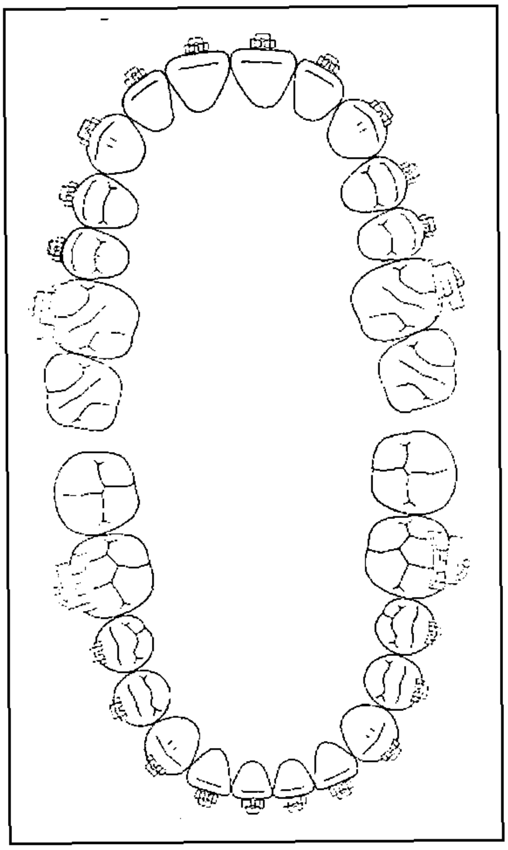


Fig. 16. Brackets are centered mesiodistally on the labial and buccal tooth surfaces.

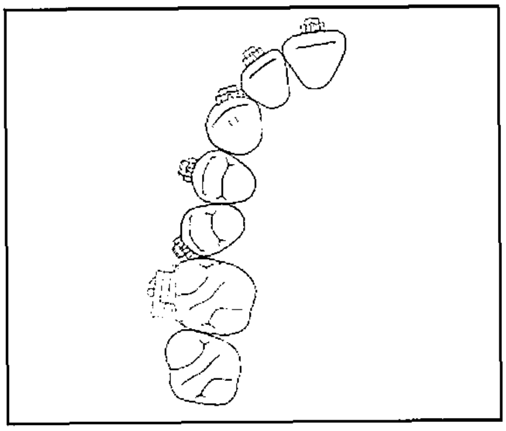


Fig. 17. Note off-center positioning of brackets on right second premolar and right cuspid. Ultimate archwire engagement will result in these teeth being held in positions of overrotation for the duration of treatment.

Rotating Springs

Rotation springs provide an easy means of rotating teeth without removing the archwire. They are preformed from .014" round wire to cause teeth to rotate about their long axes in either a clockwise or counterclockwise rotation - as viewed from the occlusal. Springs are usually inserted from the gingival (Fig. 18).

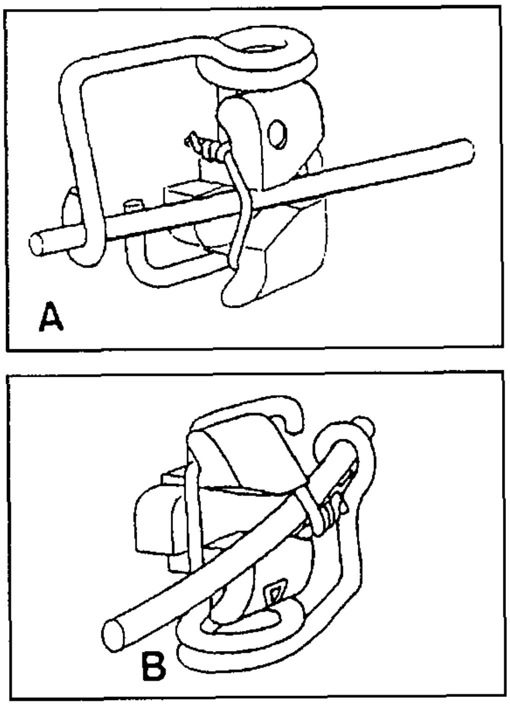


Fig. 18. Counterclockwise rotating spring in place on A, upper canine and B, lower anterior.

Uprighting Springs

Uprighting springs are used to move roots in a mesiodistal dimension following the tipping of the crowns to their final positions. Side winder springs which sit labial to the bracket are used and these are engaged from the incisal. They are available in two types. The first type sit labial to the elastomeric ligature and are placed after the ligature is engaged. The second type is placed under the

ligature which allows the elastomeric to be refreshed periodically during Stage III. Accidental loss of the spring is also discouraged. Side winder springs are prewound from 0.014" Wilcock stainless steel wire and are available for clockwise or anticlockwise uprighting (Fig. 19).

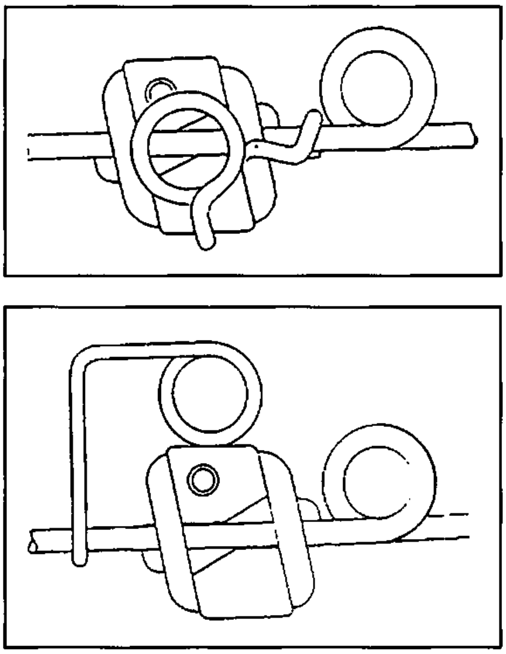


Fig. 19. Counterclockwise side-winder uprighting spring in place on an upper canine, (top) and a standard spring on the same tooth (bottom).

Power Pins

Power pins are an ideal auxiliary for engaging removable elastics or any type of fixed elastomeric. Unlike ordinary power hooks, power pins are optional and may be inserted into the vertical slot from the incisal or gingival of any bracket at any time. A specially designed, low profile head with a 15 degree inclination eliminates the need for left and right pins. They can be inserted or removed while both the archwire and ligature remain in place (Fig. 20)

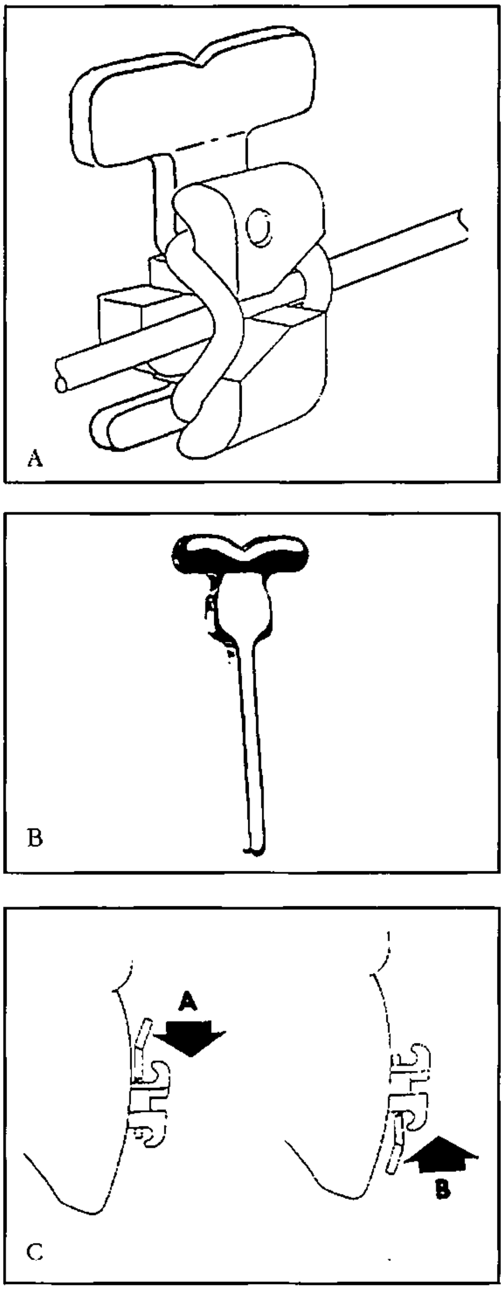


Fig. 20. A - Power pin in place, ready to accept an elastomeric from either the mesial, distal or incisal.

B - Power pin.

C - When power pin is inserted from the gingival A, the head is inclined labially, when from the incisal B, it leans lingually.

Archwire

Treatment is usually initiated using upper and lower plain archwires bent from .016" round hard nonrelaxing wire. The best wire currently available is produced by A J Wilcock of Australia and is pulse straightened premium plus archwire. If soft, relaxing or smaller diameter wire is used, the force generated will not be sufficient to control the anterior teeth and the anchor molars. If larger diameter wire is used, the forces from the bite opening bends could be so great that the anchor molars could tip distally rather than remain upright.

If bite opening and anteroposterior arch correction is not required, in a non extraction alignment case only, the initial archwire could be a low modulus archwire of larger dimension in either a round or rectangular configuration. A .019 by .025 copper nitinol type wire is most efficient for initial alignment. These wires must not be used when intermaxillary elastics are required.

Because it is not crucial that all anterior teeth be engaged in the bracket slots, there is no need to bend loops in the archwires. These loops only interfere with bite opening and vertical control and usually result in the use of more archwires than would otherwise be necessary. Small segments of flexible wire may be used in conjunction with plain .016" archwires to align crowded anterior teeth in premolar extraction cases. This procedure promotes more rapid anterior bite opening, improves molar control and reduces the number of archwires required to treat a specific case.

Archwires cease to be a source of tooth moving forces after the conclusion of Stage I. They then assume the role of retainers to maintain changes in arch form and occlusal plane that have been achieved. Therefore, to provide greater stability against the forces of occlusion, space closing elastics and ultimately torquing auxiliaries, heavier (.022" diameter) round archwires are used during Stage II and possible Stage III.

Full size (.0215" by .028") rectangular archwires may be used through Stage III to allow full expression of the preadjusted torque designed into the bases of Tip Edge brackets. Side winder springs are used to power the uprighting / torquing surfaces of the archwire slot against the flat upper and lower surfaces of the rectangular archwire. This results in desired crown torque (Fig 20)

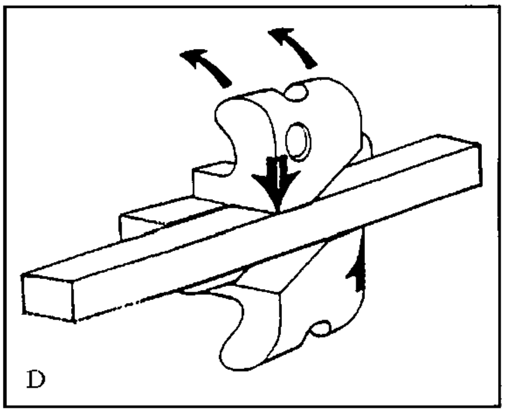


Fig. 20. D - Three-dimensional control is available from a rectangular archwire if desired.

Tip Edge Technique

Orthodontic treatment using Tip Edge brackets follows the same pattern as with traditional ribbon arch brackets being divided into three or four stages. It is desirable to distinctly separate each stage before proceeding into the next but experienced operators are able to merge stages together.

STAGE I

During Stage I, the crowns of the six anterior teeth of each arch are tipped towards their final positions. The Tip Edge bracket allows distal tipping of all anterior teeth

during this stage. Simultaneously, the incisor relationship is corrected either by opening or closing the bite. The teeth are moved from a balance of forces provided by 0.16" Pulse-straightened Premium Plus Wilcock archwire and light intermaxillary elastics (Fig.21). As the teeth are free to tip, only light forces are required and this level of force minimises side effects on the mandibular muscle sling. As with the traditional Begg appliance, premolar teeth are not bracketed or engaged in the archwire until the overbite has been corrected and the canines are in a Class I relationship.

The objectives of Stage I are the same as with traditional Begg treatment.

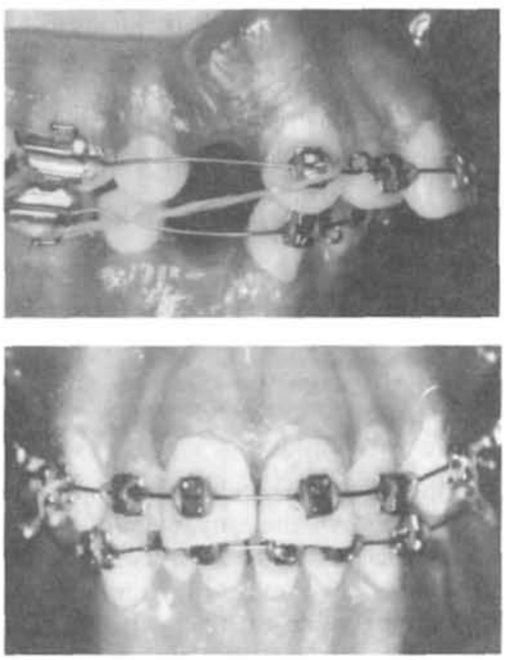


Fig. 21. Appliances in place at the start of stage I. High tensile .016" archwires with strong anchor (bite opening) bends in both arches. Anterior tooth alignment to be achieved by flexing of the archwires and stretch of elastomeric rings. Mandibular right lateral incisor is tied to archwire by elastomeric through vertical slot. Note canines are free to slide distally on archwires as anterior teeth align. Light, 2 ounce, Class II intermaxillary elastics should be worn continuously until the anterior teeth are edge-to-edge.

STAGE II

Stage II is merely to close any remaining extraction spaces from the desired direction. In a non extraction case there will be no Stage II. However, engagement of premolars is necessary before proceeding into Stage III in a non extraction case. For an extraction case, after the objectives of Stage I have been reached, early in Stage II the premolar teeth are bracketed and the archwires reshaped to engage these brackets. This involves removing the anchorage bends and replacing them with a slight anchorage curve to maintain bite opening. Arch expansion can usually be reduced and slight toe-in placed in the distal of the archform. Judicious space closing can proceed along this initial 0.016" Stage II archwire.

When all teeth are engaged in the archwire, 0.022" Stage II archwires are constructed. These archwires are essentially the same shape as the initial 0.016" Stage II archwires but with ideal arch form and slight toe-in. Once the overbite has been corrected and Stage II commenced, the rectangular tube on the anchor molar is used instead of the round tube (Fig. 22). This increases molar control, especially with the heavier wires to be used subsequently, and establishes correct vertical relationships between the posterior teeth. Buccal expansion is usually not required with this heavy archwire which merely acts as a passive wire along which the teeth are tipped to close excess extraction spaces. As extraction space is finally closed, small molar offsets may be placed in the archwires if rectangular wires are to be used in Stage III. These molar offsets with increased toe-in facilitate the insertion of full sized rectangular archwires for Stage III.

If all space is to be closed by tipping anterior teeth distally, elastomerics or elastics are used with light forces to tip anterior teeth distally.

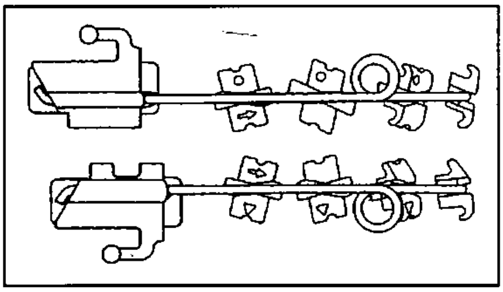


Fig. 22. B - Relationships between tip-edge archwire slots and straight archwires at the end of stage II during treatment of class II, division 1 malocclusion with removal of first premolars.

However, if spaces are to be closed from the rear, a braking mechanism may be placed on the anterior teeth as in the ribbon arch Begg appliance. Side winder springs on lateral incisors and canines prevent these teeth tipping distally and heavier space closing forces shift the emphasis on space closure to the rear.

Elastomeric links (E-links) are a reliable method of intramaxillary force. They do not need to be changed and remain active for at least three months. They are available in eight sizes (Fig 23) but the size E-5 is suitable for premolar extraction cases. E-links may also be used from the lingual of the anchor molar as shown in the following diagram (Fig. 24). The E-link is initially placed around the anterior portion of the archwire between the canine and the lateral incisor and then the distal tab is engaged over a lingual button or hook. This type of attachment is not irritating to the tongue.

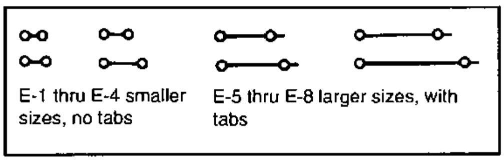


Fig. 23.

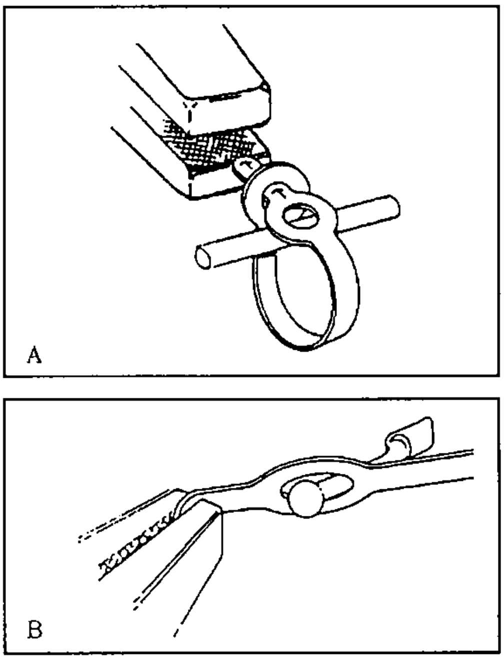


Fig. 24. A, The longer sizes of e-links 5 to 8, have a unique tab on one end that facilitates the initial attachment around an archwire, and B, the ultimate engagement over a hook.

STAGE III

During Stage III, root angulations of tipped teeth are corrected within all three planes. This involves mesiodistal tipping of most teeth and torquing of the four incisor teeth. The round stage II archwires may be used for Stage III or full size 0.0215" X 0.028" rectangular archwires may be employed.

These heavy archwires maintain all corrections achieved during Stage I and Stage II and serve as a base from which the root moving auxiliaries can effect axial changes. As the base arch is heavy and the auxiliaries moving the roots are light, reciprocal effects are negligible and vertical changes controlled.

The objectives of Stage III are the same as for the traditional Begg appliance.

STAGE III APPLIANCE USING 0.022" ROUND BASE ARCHWIRES

The Stage II archwires are reshaped to ideal arch form with slight reverse curve if necessary to maintain overbite correction. Slight toe-in of the anchor molars may be necessary. The distal end of the archwire which protrudes past the rectangular molar tube must be annealed. Any overcorrections placed in the archwire during Stage II may be maintained during Stage III.

A torquing auxiliary for anterior teeth is bent or selected. These auxiliaries are generally used for labial or lingual root torque on the four upper incisors only. Torque for other anterior teeth is usually provided by means of a rectangular Stage III archwire as described in the next section. However, in special circumstances, labial root torque may be needed on a previously palatally impacted upper canine or a spur torquing auxiliary for lingually placed lower lateral incisors may be needed if over torquing is required for long term stability.

The torquing auxiliary is placed first in the bracket slot (Fig. 25) and the Stage III archwire inserted through the rectangular molar tubes and placed over the auxiliary. An individual root torquing auxiliary may be used for selected upper or lower individual teeth. This auxiliary can move roots buccally or lingually as shown in Fig. 28. The free end of the longer arm must be long enough to reach one tooth past the canine and is seated lingual to the main round archwire. All teeth are ligated with elastomeric rings and side winder springs are placed on all teeth requiring mesiodistal axial correction (Fig. 26). If invisible side winders are used they are placed before the elastomeric ligatures. Standard ribbon arch bracket root tipping springs or mini-springs (A J Wilcock) may be used instead of sidewinders (Fig. 27). The distal end of the archwire is cinched firmly to prevent anterior space reopening.

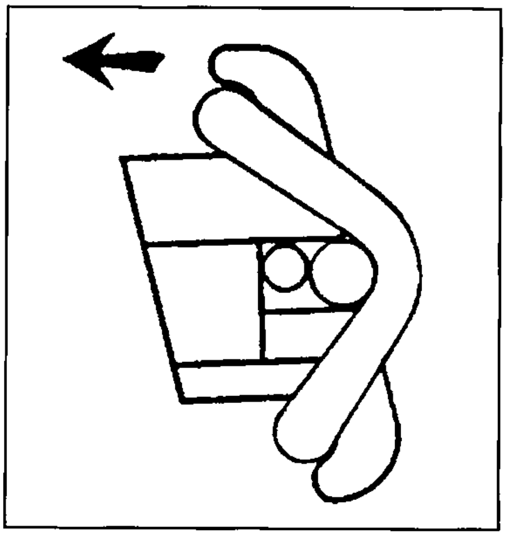
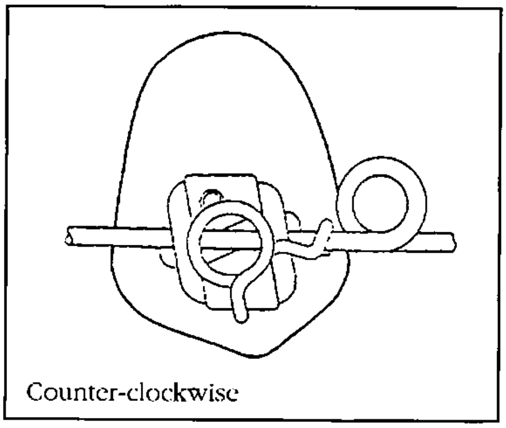
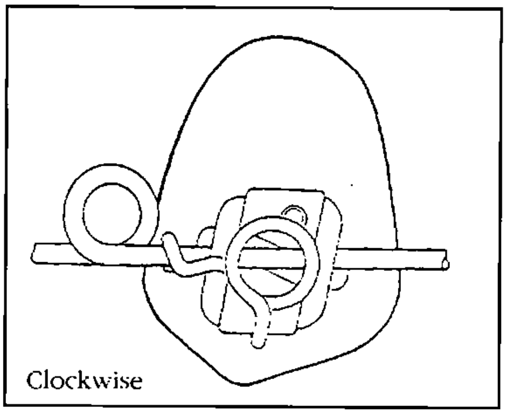


Fig. 25. Torquing auxiliary (small circle) is placed in archwire slot ahead of main .022" round archwire (large circle).





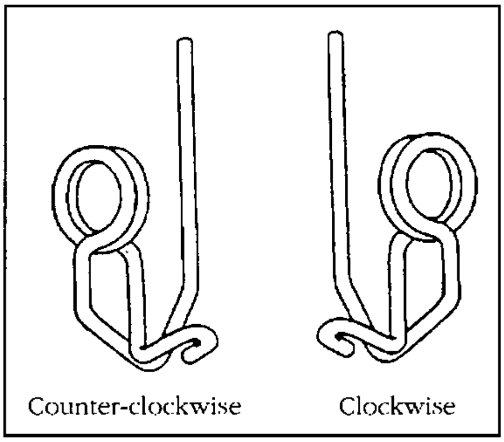


Fig. 26. Side winder springs in place on maxillary canines.

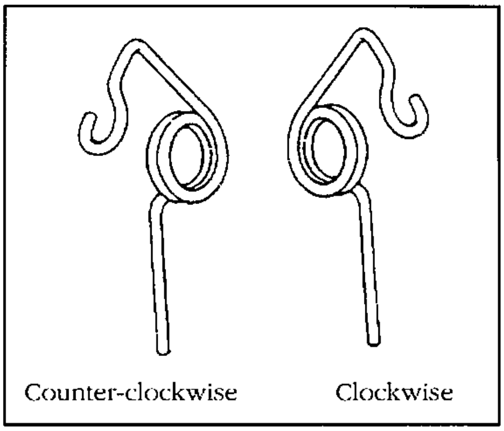
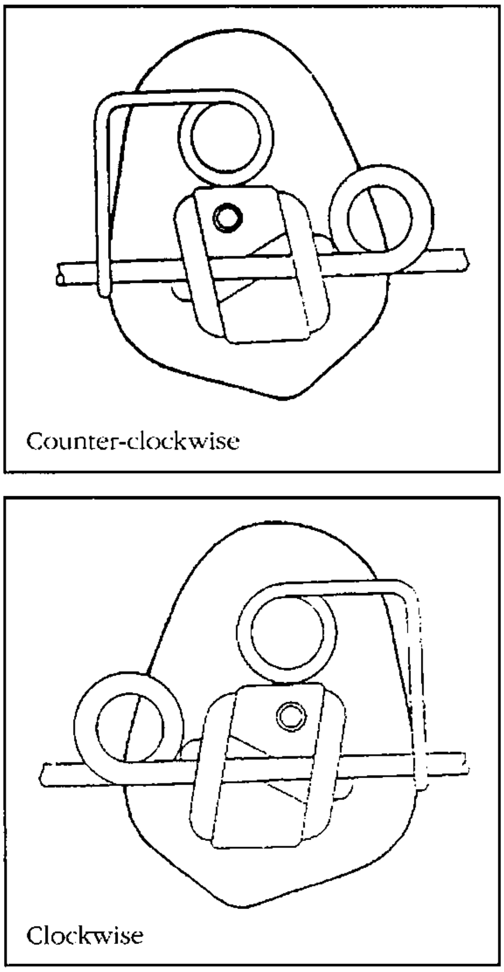


Fig. 27. Standard uprighting springs as would normally be used on maxillary right and left canines.



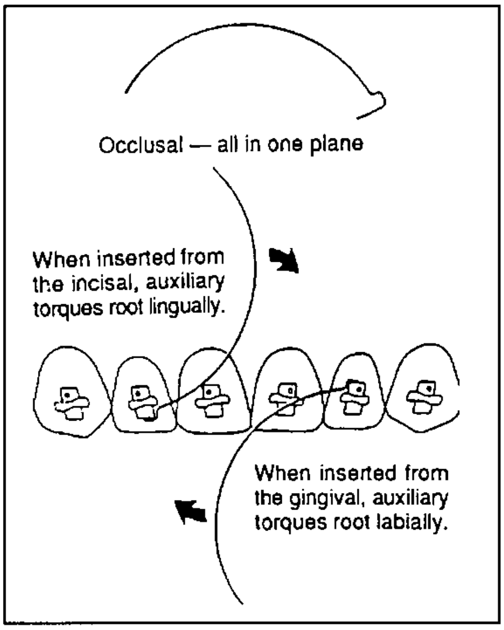


Fig. 28.

This type of Stage III assembly is utilised when significant torque is required for incisor teeth or if selected overtorquing is required for long term stability. The following section describes the use of rectangular wires for Stage III torque but it is not possible to over torque selected teeth without complicated third order bending of the rectangular wire.

STAGE III APPLIANCE USING 0.022" ROUND BASE ARCHWIRES

The Stage II archwires are reshaped to ideal arch form with slight reverse curve if necessary to maintain overbite correction. Slight toe-in of the anchor molars may be necessary. The distal end of the archwire which protrudes past the rectangular molar tube must be annealed. Any overcorrections placed in the archwire during Stage II may be maintained during Stage III.

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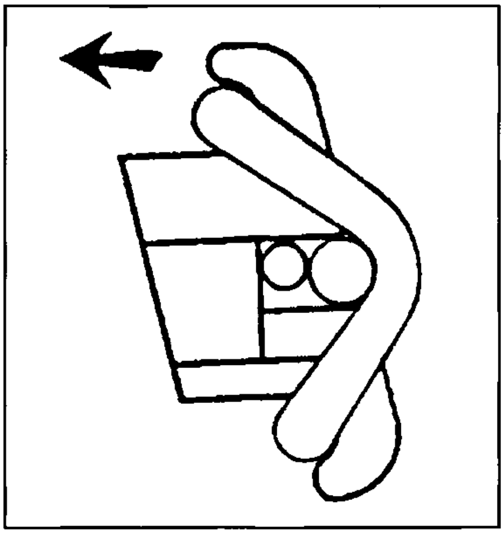

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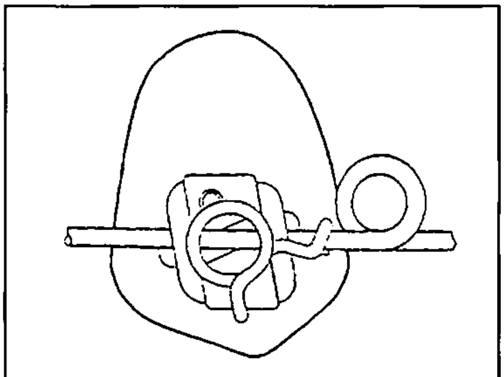
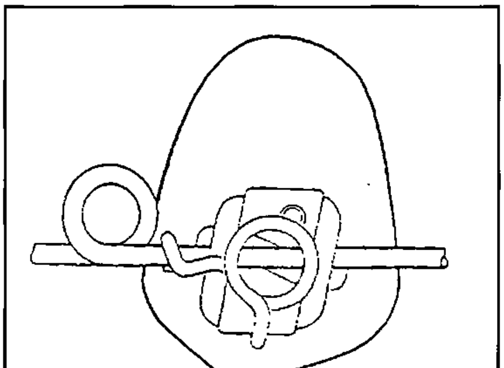


Counter-clockwise



Clockwise

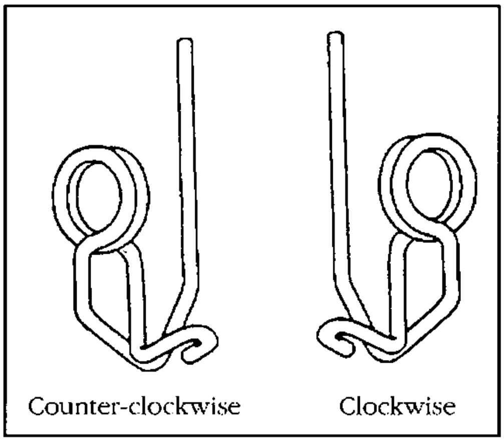


Fig. 26. Side winder springs in place on maxillary canines.

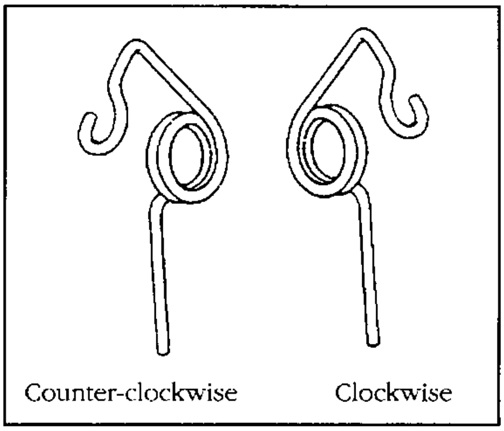
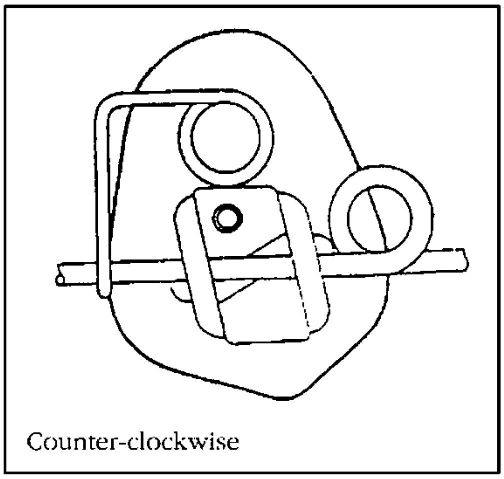
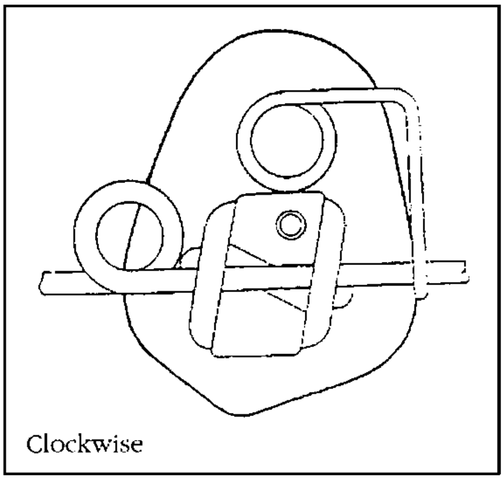


Fig. 27. Standard uprighting springs as would normally be used on maxillary right and left canines.





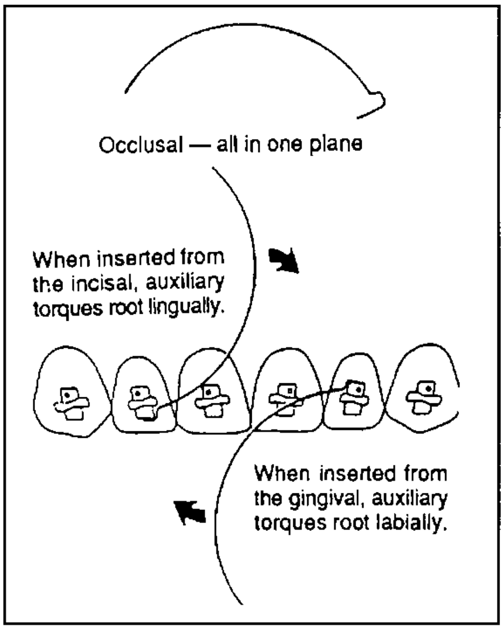


Fig. 28.

This type of Stage III assembly is utilised when significant torque is required for incisor teeth or if selected overtorquing is required for long term stability. The following section describes the use of rectangular wires for Stage III torque but it is not possible to over torque selected teeth without complicated third order bending of the rectangular wire.

STAGE III AND FINISHING WITH RECTANGULAR ARCHWIRES

The rectangular wire facility enables the Tip Edge appliance to achieve its preprogrammed finish positions in all three dimensions (Fig 1). Ordinary straight wire appliances establish finishing inclinations relatively early in treatment, causing subsequent translation of the teeth to be heavy on anchorage. However, the Tip Edge appliance allows ease of tooth movement during Stages I and II using light forces and, therefore, requires less anchorage. Finishing angulations are adopted only when they are necessary - towards the completion of treatment.

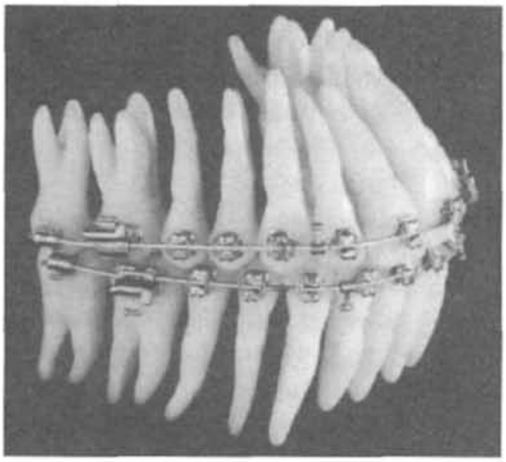


Fig. 1. Torque and tip finishing prescription of Rx-I brackets is fully expressed with flat .0215" x .028" archwires.

Furthermore the manner in which third order torque is achieved with Tip Edge brackets is fundamentally different from any previously known appliance. All conventional edgewise base systems rely on activity in the rectangular archwires to achieve torque forces which are transmitted to each root via a rigid bracket slot. Inevitably, an active archwire will itself be deflected when engaged into the archwire slots, causing an undesired root reaction in the adjacent teeth. This occurs in conventional horizontal slot brackets during both second and third order torque movements.

The Tip Edge concept is different because the bracket opens its archwire slot from .022" to a maximum of .028" during tipping of the teeth in earlier treatment stages (Fig 2). Rectangular arches can, therefore, engage the slots without deflection. The bracketed teeth are then uprighted three-dimensionally to the archwire under the progressive action of Side Winder auxiliaries. Accurate rectangular control within the molar tubes is ensured throughout, since the archwire itself cannot be torqued by the brackets.

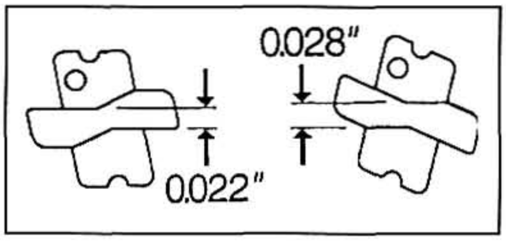


Fig. 2. Unique ability of tip-edge archwire slots to increase in size as crowns tip facilitates change to larger size archwires.

Edgewise Archwires

Rectangular arches can be used throughout Stage III, conferring additional molar control and, where required, buccal segment torque. It is also possible to provide anterior anchorage reinforcement as may be appropriate in certain cases.

The Dynamics of Rectangular Stage III

Apart from greater archwire rigidity, the effect of rectangular wire within Tip Edge brackets at the outset of Stage III will be no different from round wire. This is because the teeth will be in distally tipped positions

following Stage I and II (or mesially tipped in the case of second premolars where first premolars have been extracted). The slots of all brackets will, therefore, be opened to sizes effectively greater than the .0215" of the archwire. Opposing torque surfaces will not be in contact with the archwire at this stage. However, the precise fit of the rectangular wire within the molar tubes ensures immediate molar torque control.

As second order root uprighting progresses during Stage III under the influence of side winder springs, the bracket slots close down. The torque surfaces make increasing contact with the flats of the rectangular wires as the prescribed crown tip and torque inclinations are approached (Fig 3). Activation of the arms of side winder springs should not be relaxed at this point, but should be maintained at a maximum of approximately 90 degrees to the archwire. The torque surfaces will then be pressed into tighter and flatter contact with the rectangular wire, inducing third order torque.

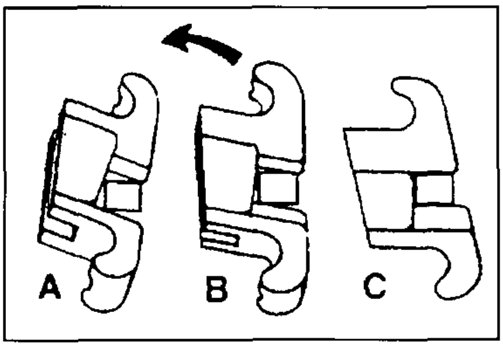


Fig. 3. A, B, C - Third order movement (palatal root torque) is created by second order movement (uprighting of crowns) by side-winder springs in the presence of a rectangular archwire. A - Initial engagement of rectangular wire - no flexing as slot is wide open. B - Slot begins to close down in on both sides of wire resulting in torque (arrow). C - Final crown tip and torque are achieved simultaneously when slot closes completely.

Full bracket engagement is, of course, essential for this effect to be transmitted. Third order torque movements (except to the molars) are, therefore, achievable only as second order uprighting progresses. The third order forces at the apex generated by the side winder springs amount to between 20 and 30 grams (up to approximately 1 ounce), sufficient to allow effective root movement without risk of excessive force.

Both torque and tip reach completion simultaneously and are self limited according to the angulation of the archwire (normally zero torque).

In extraction cases, it is frequently the mandibular incisor teeth that are uprighted quickest by the side winders. These units are then available to offer some degree of anchorage reinforcement, while the premolars and canines continue in second order uprighting. For this purpose, the incisor Side Winders should be left in place, fully activated. It is not normally necessary to modify the base archwire to enhance this effect.

Bonding Heights

As with any pretorqued appliance, variations in bonding height can result in small differences of final torque angulation, and can adversely effect the efficiency of the torquing process. A mid-crown bonding position is, therefore, recommended as described by Dr L F Andrews, (Fig 4), rather than a more incisal bonding height. Bonding jigs can readily be modified to achieve the desired bonding positions simply by cutting off the occlusal rests. The vertical arm of the jig can be aligned with the long axis of the crown at its midpoint, while the vertical placement at mid-clinical crown height can be gauged by eye. The advantage of a mid-crown bonding position is that it coincides with the point of greatest crown

convexity. It will, therefore, automatically produce a more consistent final torque prescription, irrespective of the size of the clinical crown. It also increases efficiency of torquing, compared with an incisal bonding position, because it is less distant from the root itself.

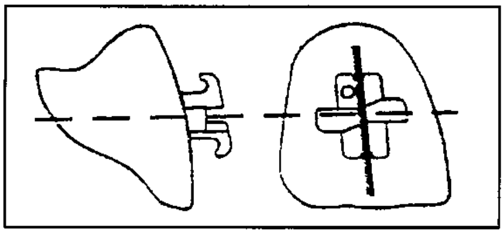


Fig. 4. The mid-crown bonding position, as originally described by Dr. L.F. Andrews

Preparation for Rectangular Stage III

Insertion of .0125" X .028" rectangular arches at the start of Stage III is not difficult, provided the archwires are similar in shape to the Stage II round archwires that they replace. However, the vertical relationship between the rectangular tubes and premolar brackets needs to be particularly accurate due to the precision fit of the archwire within the molar tubes. The following Stage II sequence ensures a smooth transition from round to rectangular treatment phases.

At the conclusion of Stage I, as the premolars are bonded, the existing .016" round archwires should be modified with bite opening vertical curvatures instead of anchor bends. These archwires are now inserted into the rectangular molar tubes instead of the round tubes (Fig 5). The wire is generally flexible enough to elevate the newly bonded premolar brackets to a level matching the rectangular tubes. In cases of deeper submergence of the premolars, the round tubes can be engaged initially and the rectangular tubes after a short treatment interval.

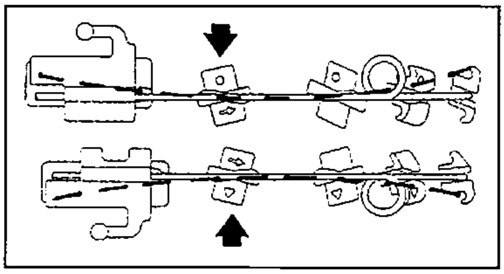


Fig. 5. At the end of stage I, premolars can be bonded and elevated with original .016" archwires. Note localized anchor bends must first be removed and replaced by gentle overall "curvatures".

Once premolar alignment has been achieved, Stage II can be commenced using .020" or .022" round archwires. The rectangular .022" X .028" molar tubes are designed with sufficient tolerance to allow free sliding along a .022" archwire, where maximum stiffness is required such as across first molar extraction spaces, or when producing arch expansion. However, .020" archwires are normally adequate. Overbite reduction should be maintained by means of gentle bite opening curves.

Space closure can be accomplished using horizontal E-Link elastomerics, while maintaining an exact vertical relationship between the premolar brackets and molar tubes without the need for offsets.

At the final adjustment of Stage II, when space closure is virtually complete, a 1mm buccal offset with 10 degrees of toe-in should be placed in the archwires immediately mesial to the molar tubes. This eliminates any small mesial rotation of the molars and greatly facilitates the insertion of the rectangular archwires at the subsequent visit.

Setting Up Rectangular Stage III

Archwires should be .0215" X .028" rectangular stainless steel with arch form similar to the round wires in Stage III. It is not

necessary to incorporate any contraction across the maxillary molars or expansion across the mandibular molars in order to resist the effects of anterior torquing or Class II traction, as may be required when using round archwires. Neither are loops, circles or stops required in the archwire.

Crimpable hooks (TP 226-010) should be placed midway between the canine and lateral incisor brackets on each arch, facing gingivally. These can be crimped directly in place on the archwire with a special plier (TP 100-172). Maxillary and mandibular arches should be checked for arch width and correlated carefully.

In cases with an initial reduced overbite or anterior openbite, the rectangular arches may be fitted "flat" without vertical curvatures (TP 381-197 maxillary, 381-198 mandibular). However, usually a "rocking horse" curve in the maxillary archwire and a gentle reverse curve of Spee in the mandibular archwire will be necessary to maintain overbite reduction, again similar to round wire arch form. If so, third order adjustment may be required in the anterior and posterior sections of the archwire (Fig 6A & B).

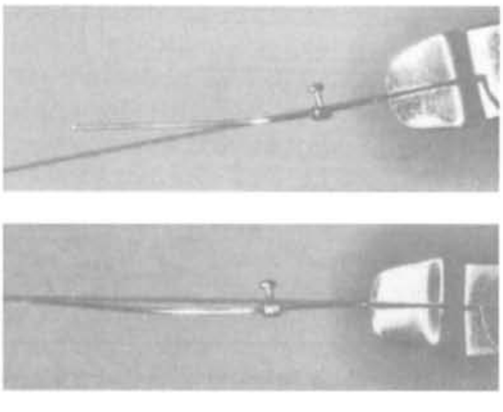


Fig. 6. A - Bite opening curves in rectangular archwires cause undesired anterior labial crown torque

B - Zero crown torque is restored in anterior segment.

As can be seen from Figure 6A, bite opening curvatures in the buccal segments in either maxillary or mandibular archwires will automatically introduce labial crown torque in the archwires across the incisors. This could eventually provoke incisor proclination and possible protrusion.

Therefore, unless using pretorqued archwires it will usually be necessary to compensate by inserting sufficient lingual crown torque across the incisor segments of the archwires (between the hooks) to restore zero torque (Fig 6B). The flat torque surfaces would, therefore, then be parallel to the mean occlusal plane (zero torque) which will neither add nor subtract from the Rx-I torque-in-base bracket description.

However, adjusting the anterior torque as mentioned above will automatically induce unwanted lingual crown torque back to the buccal segments, due to the continuity of the archwire. The canine, premolar and molar section of the archwire will, therefore, need to be readjusted to zero torque. This is a simple adjustment, made by grasping the archwire with two pairs of torquing pliers (TP 100-142P) immediately adjacent (one on each side) to each traction hook (Fig 7). A small twist at this point can return the unwanted lingual crown torque along the posterior segments to zero torque without disturbing the anterior torque setting (Fig 8).

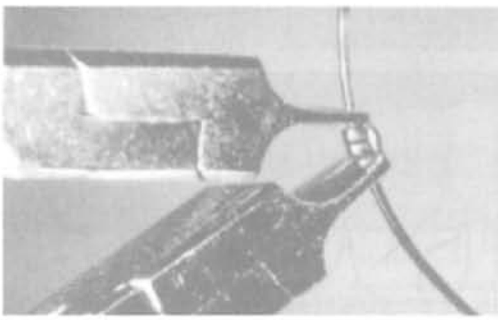


Fig. 7. Adjusting the posterior segments back to zero torque.

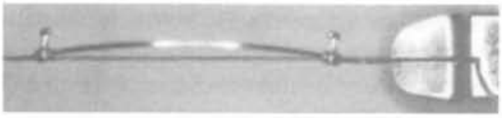


Fig. 8. Posterior section of the archwire after readjustment to zero torque.

The crimp-on hooks, therefore, make ready markers as the points on the archwire between which incisor torque should first be adjusted and distal to which buccal segment torque is subsequently removed. (*For this reason, placement of the hooks on the archwire is recommended before making torque adjustments. Crimping the hooks after arch placement in the mouth risks distorting the torque adjusted into the archwire, due to the compressive effect of the crimping plier.*)

Before placing the archwire, recheck molar torque and arch width by trying the ends into their respective molar tubes, one at a time.

Archwire length should be tailored precisely, leaving only 2mm projecting distal to the rectangular tubes. Insertion is made easier by thinning out the projecting ends from the lingual (Fig 9). It is essential to anneal the ends thoroughly. Once placed, turning the distal arch ends gingivally by only 10 degrees is sufficient to prevent spaces reopening during root uprighting. Bending the archwire ends through a greater angle is unnecessary, making subsequent removal difficult. Furthermore, cinching tightly can exert contact point pressure, which may impede the action of the side winder springs.

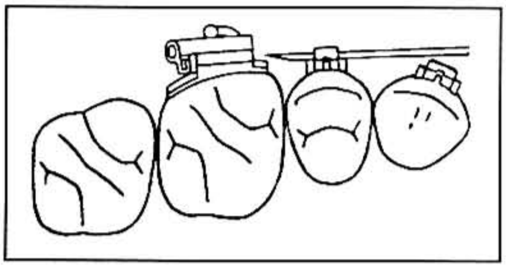


Fig. 9. End of rectangular archwire is thinned from the lingual to facilitate insertion into occlusal molar tube.

Use of Pretorqued Archwires

With the introduction of pretorqued archwires (TP 381-195 & 381-196) anterior torque adjustment to compensate the bite sweeps in increased overbite cases is seldom necessary. The torque provided in each archwire (lingual crown torque 5 degrees maxillary, 8 degrees mandibular) will automatically cancel out the labial crown torque that would otherwise result from the vertical curvatures. Again, the aim is to produce approximately zero torque across the incisor segments as described previously and illustrated in Figure 6B.

To safeguard against incorrect preparation and insertion, maxillary archwires have a single line etched on their *gingival* surfaces at the midline; mandibular archwires have double lines etched on their *occlusal* surfaces. The etched centreline markings on both maxillary and mandibular archwires should, therefore, be visible to the operator at all times and when the archwires are in place, thereby preventing accidental torque reversal by fitting the archwires upside down (Fig 10).

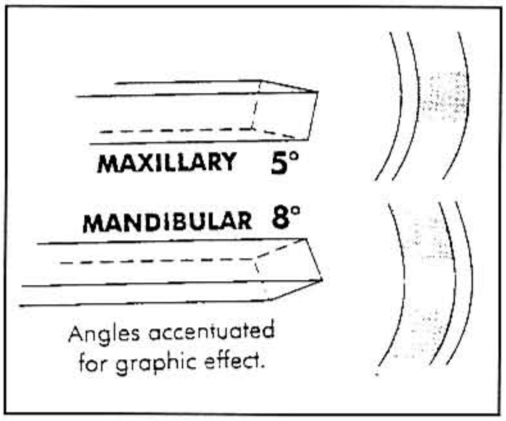


Fig. 10. Pretorqued archwires - 5° of lingual crown torque (maxillary) and 8° (mandibular). The centerline markings on the upper surfaces should both be visible to the operator on insertion.

Both archwires share the same dimensions as the untorqued archwires and the pretorque extends throughout the arch to the distal ends. It is, therefore, possible to accommodate to variations of tooth width and arch form without stocking a range of different sized archwires. Having optimized arch width, placed crimp-on hooks, and prepared the arch ends as previously described, it is only necessary to wipe in the bite sweep and return the posterior to zero torque (Fig 7 and 8).

Small alterations to anterior torque can easily be made by holding the archwire firmly at its centreline in a plier. Gentle upward pressure with fingers beneath the distal ends will slightly increase labial crown torque in the maxillary anterior segment, while depressing the ends will reduce it and vice versa in the mandibular anterior segment. If making torque alterations at the front, be sure to recheck for zero torque in the posterior segments.

Skeletal Compensation

The torque values built into the bases of the Rx-I Tip Edge bracket for anterior teeth are appropriate for standard finishing of Class I apical base malocclusions (Fig 11). In severe skeletal cases, however, normal incisor torque angulations may not be appropriate. The most common need for a modified anterior torque prescription arises in Class III cases, where it is usually necessary to finish the mandibular incisors to a retroclined position in order to maintain a positive overjet. Since the majority of Class III cases have a raised mandibular angle with reduced overbite, a mandibular pretorqued archwire can be used without a bite sweep. This will then give 8 degrees of retroclination to the mandibular incisors. All that is required is to adjust the segments distal to the hooks to zero torque, as described previously.

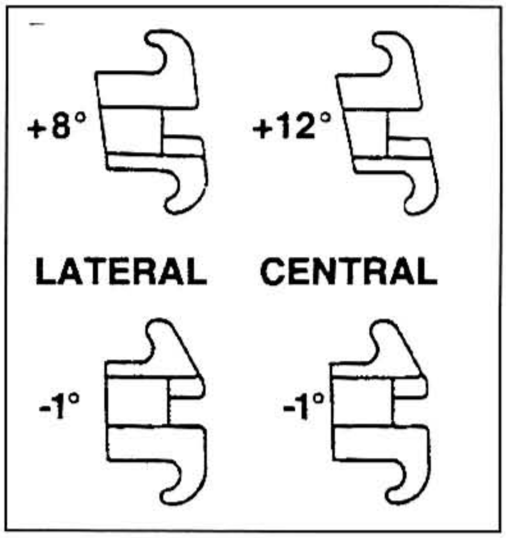


Fig. 11. Torque values in bases of Rx-I series tip-edge anterior brackets are designed for class I apical base cases.

In severe Class III cases some proclination of the maxillary incisors may also be required. For this purpose it will be necessary to fit a maxillary pretorqued archwire upside down. In this instance, the centreline marking will not be visible to the operator on insertion. With no bite sweep, 5 degrees of proclination will automatically be provided to the maxillary incisors (Fig 12).

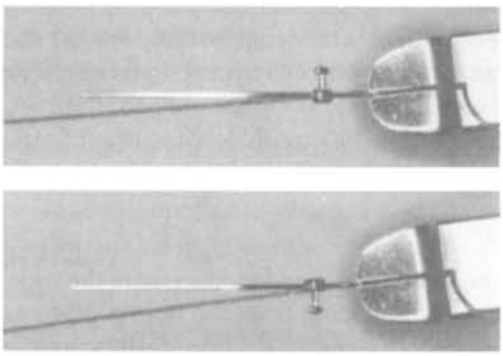


Fig. 12. A, B - Compensating a class III skeletal pattern without increased overbite. A, Pretorqued archwire can be fitted flat to produce 8° of retroclination of the mandibular incisors. B, The maxillary archwire must be fitted upside down to allow 5° of maxillary incisor proclination.

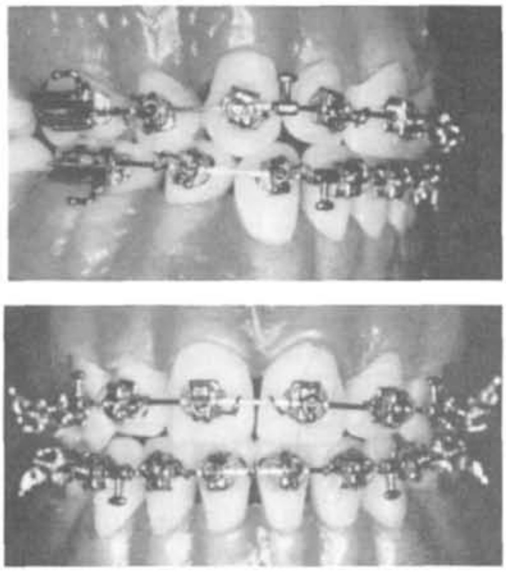


Fig. 12. C - Rectangular stage III, full size (.0215" x .028") archwires in place in both maxillary and mandibular arches. Side-winder springs provide force to achieve final tip and torque angles for all teeth. Archwires remain passive for maximum control of molars and the vertical dimension. Intermaxillary elastics are worn as required to maintain anterior tooth relationships.

Torquing with Rectangular Archwires - The New Tip-Edge Concept

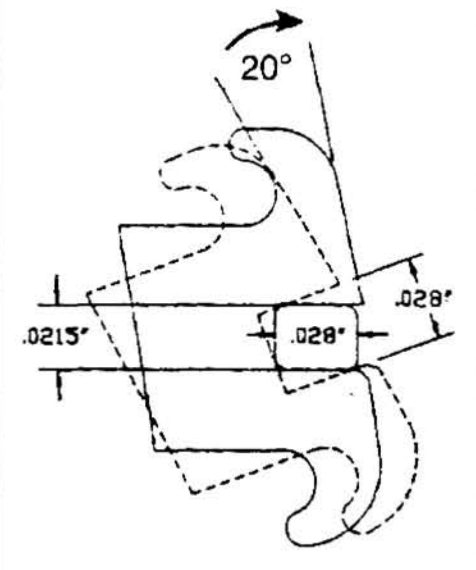
The Tip Edge concept of a slot that opens and closes offers a unique innovation in root torquing. Instead of increasing rectangular archwire sizes progressively to fill the archwire slot, as with conventional edgewise based systems, Tip Edge "shrinks" the vertical bracket dimension down to fit a full size, passive rectangular archwire.

The effect of side winder springs working in combination with rectangular archwires is the same for all bracketed teeth. In the process of uprighting from the tipped position, each tooth is controlled individually to its self-limited, three-dimensional finishing position, according to the torque built into each bracket, also the adjustment of the archwire at the start of Stage III (normally zero torque).

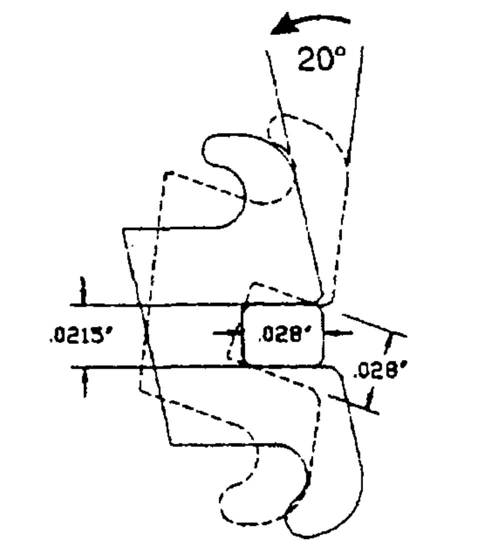
Again, unlike conventional edgewise or "straight wire" systems, each tooth is torqued without any unwanted torque reaction upon the neighbouring teeth. Light, uniform torque forces are maintained between treatment visits, since activation is derived from side winder springs rather than the archwire itself. Excessive torque forces are, therefore, impossible.

Torque values fed to the molar tubes remain the same throughout third stage, conferring undisturbed molar stability. All torquing of the bracketed teeth is accomplished with a single archwire and, with experience, can be achieved without the need for midstage archwire adjustments.

Furthermore, teeth can be recovered from greater angles of torque divergence than would be possible with conventional brackets. From maximally tipped positions, torque variations of 20 degrees in either direction (Fig 13) can be accommodated within the brackets without deflection of the archwire or need for adjustment during the third stage process.



Maxillary lateral incisors



Maxillary central incisors

Fig. 13. Torque can be retrieved from up to 20° either side of the finishing value, without need for adjusting or deflecting the base archwire.

Use of Torque Bars

An alternative method of torquing maxillary or mandibular incisor teeth is by means of nickel titanium Torque Bars in conjunction with Deep Groove incisor brackets (Fig 14).

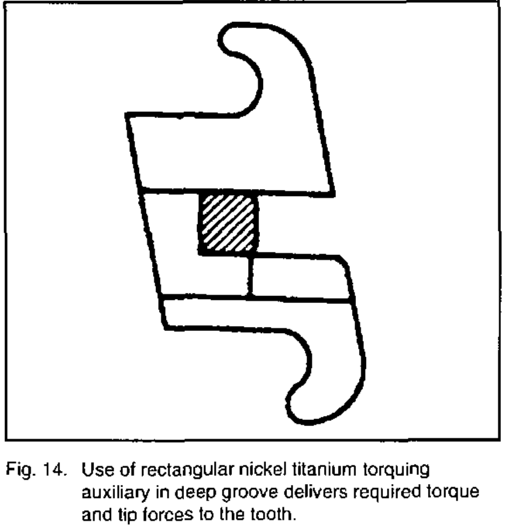


Fig. 14. Use of rectangular nickel titanium torquing auxiliary in deep groove delivers required torque and tip forces to the tooth.

This system can be used with rectangular base archwires during Stage III for those cases requiring superior aesthetics particularly across the maxillary incisor region, with a lower labiolingual profile.

However, side winder springs may be required initially to correct marked distal crown inclinations of the lateral incisor teeth before the .018" X .022" Torque Bar auxiliary can be engaged in the Deep Groove slots.

Wire ligatures must not be used when employing rectangular base archwires. Wire ligatures will inhibit the action of the Torque Bar when tightened around the square corners of the rectangular archwire.

A 30 degree torquing auxiliary will ensure incisor torque forces right up to the angle required for finishing the case. When the intended maxillary incisor torque angulations have been achieved, the Torque Bar should be removed as it is not fully self-limited by the rectangular base archwire. The Deep Grooves can be filled passively with a short section of .016" round Co-Ax wire in order to preserve correct in / out relationships during final finishing.

Alternatively a size E-9 E-Link ligated around the canine brackets can be routed through the Deep Groove slots. This similarly prevents the main archwire from entering the Deep Grooves, while preventing spacing in the maxillary anterior segment.

This concludes the section written by Dr Parkhouse.

STAGE IV

Stage III is completed when the apices of all teeth have reached their desired positions. They may be in an ideal position or there may be overcorrections built in. The incisor relationship may still be edge to edge and the interdigitation not ideal.

At this point, the clinician must decide how the case should be finished. A severe Class II malocclusion with a deep bite may be better finished with the incisors in an edge to edge relationship and the buccal occlusion showing a mild Class III tendency. During retention, one could be confident that the occlusion will settle into an excellent relationship, with the condyle in an ideal position in the glenoid fossa. However, if the original malocclusion showed a Class III openbite tendency, then it would be necessary to finish with increased overbite and some overjet. A Class II openbite malocclusion should be finished with a deep positive overbite and incisal and cuspal guidance.

Stage IV may or may not be necessary for any particular case. The type of Stage IV and methods used are not particular to the Tip Edge bracket but depend on the philosophy of the individual clinician.

The 0.022" round Stage II archwires may be convenient Stage IV archwires to incorporate any final detailing and vertical adjustment. The original Stage I 0.016" round archwires may be convenient Stage IV archwires if vertical elastics are to be used to "sock in" the occlusion and/or increase the overbite. Flexible rectangular archwires may also be used to "sock in" the occlusion if torque control during Stage IV is desirable. The axial inclination of teeth may be maintained by using Tip Edge rings during Stage IV.

Retention

There are no particular retention regimes specific for the Tip Edge technique and clinicians should use whichever methods they currently employ.

CASE REPORT

The following case report has been selected to demonstrate the versatility of the Tip Edge appliance in what may be considered by many to be an unusual treatment plan.

The patient presented at fourteen years of age with a Class II division 2 malocclusion. There was a full Class II buccal relationship and a significant division 2 incisor relationship with a deep overbite at 100% and retroclined upper incisors. The upper lateral incisors were proclined and the canines crowded buccally (Fig 1). The profile was recessive with a relatively large lower face height and an obtuse nasolabial angle (Fig 2). A cephalometric analysis confirmed the presence of a Class II skeletal relationship (Wits = 9mm) with retroclined upper incisors at 87 degrees to SN and the lower incisors 3mm behind the A - Pogonion line.

To maintain profile control and the cosmetic effect of the dentition, treatment was initiated without extractions with the aim of utilising expected normal growth to re-arrange the dentition within the skeletal frame work.

Plain 0.016" Pulse-straightend Premium Plus Wilcock archwires (Fig 3) were placed with bumper tubes to maintain the arch length between canines and first molars and to reduce any soft tissue irritation from the long span of archwire (Fig 4). Ormco Road Runner elastics (force less than 2 ounces) were prescribed and worn (as Class II elastics) full time. After six months treatment another cephalometric X-ray was taken to determine the final treatment plan. The extraction of the four second permanent molars was prescribed. The removal of these teeth was to relieve the slight crowding tendency and allow some spontaneous distalisation of the arches. The family were happy with profile changes and mandibular surgery was declined. The archwires were reshaped and the Class II elastics were changed to TP yellow (2 ounce) (Fig 5).

After ten months treatment, the incisor relationship and buccal occlusion was corrected and the premolars were bonded and engaged in the reshaped Stage I archwires. Two months later, 0.022" round archwires were placed as Stage III archwires and lingual root torque applied to the upper central incisors and side winder springs on both upper canines and lower lateral incisors (Fig 6).

Five months later a 0.0215" X 0.028" rectangular lower archwire was placed to torque the lower incisor roots labially. Side winder springs were placed on all lower incisors. Three months later the upper arch wire was reshaped as a Stage IV archwire and the appliances removed after two years of treatment. Trutain retainers were issued and worn at night time only. The occlusion settled in six months to the situation shown in Figure 6 and the extraoral photographs in Figures 8 and 9 show the facial views. Retainers were discarded after twelve months of retention.

The cephalometric tracings of treatment are shown in Figure 9. The ANB angle was reduced from 9 degrees to 4 degrees while the mandibular plane angle changed from 22 degrees to 23 degrees. The IMPA changed from 92 degrees to 93 degrees and the upper incisor angle to SN changed from 87 degrees to 91 degrees.

Fig. 2. Pre-treatment

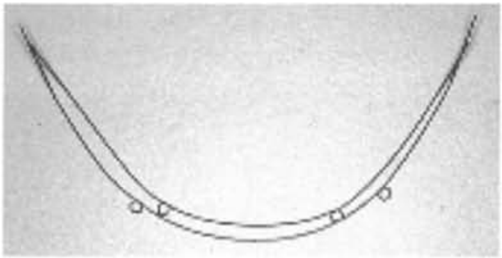


Fig. 3. Archwires

Case Report Figures

Fig. 1. Pre-treatment

Fig. 4. Initial appliance

Fig. 5. Extraction decision

Fig. 7. A, B, C - In retention

Fig. 6. Stage III

Fig. 8. A, B - In retention

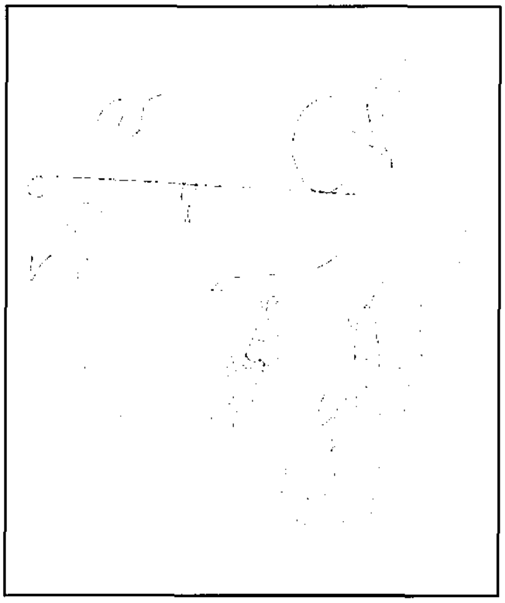


Fig. 9. Cephaiometric tracings

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12
The Pre-Adjusted Edgewise Appliance

Peter Fowler

INTRODUCTION

The Edgewise appliance was originally developed by Angle (1928) following earlier experiences with other forms of fixed appliances. The earliest of these was Angle's E Arch (1887), which was capable of simple tipping of the teeth for alignment. The pin and tube system (1910) allowed greater control in tooth movement but it proved inpractical in clinical use. The ribbon arch appliance (1916) was the first to use archwires that were rectangular in cross section and these were pinned into a vertical slot. The appliances were designed for expansion followed by labial or buccal root torque as required. Although the rectangular archwire could be twisted as it was inserted into the vertical slot the resiliency of the wires used at that time allowed only limited repositioning of the roots.

To overcome limitations in the ribbon arch, Angle (1928) re-orientated the bracket slot horizontally and inserted the rectangular archwire with its wider edge or dimension horizontal, hence the term ***"edgewise"***. This allowed three dimensional control over tooth movement which was more precise and easier to manage than with his previous appliances. To obtain the desired tooth movements, however the archwires had to incorporate many time consuming and technically demanding archwire bends.

The "standard" edgewise brackets of today are essentially very similar to those originally used by Angle. These appliances rely upon the placement of archwire bends to obtain three dimensional control of each tooth position within the arch. Although most of the subsequent changes to the Standard Edgewise appliance have been in an attempt to reduce the amount of wire bending required, the most important design feature, the rectangular archwire slot, has been retained. This still remains the most effective bracket slot for controlling teeth in all three planes of space when used in combination with a rectangular archwire.

The subsequent modifications to the standard edgewise appliances have resulted in the placement of the primary source of tooth control in the bracket, rather than relying upon routine archwire manipulation. These are referred to as the ***"preadjusted" edgewise*** brackets. The preadjusted edgewise brackets may be partially or fully preadjusted depending upon their design features. The ***"straight wire***

appliance" is a term that is sometimes used to describe the fully preadjusted appliance, although it is in fact, the trade mark of 'A Company' (San Diego, California, USA) who were the first to develop and market a fully preadjusted appliance.

Today there is a wide selection of various Standard and Preadjusted edgewise brackets available. This reflects a wide divergence of techniques and treatment philosophies and there are many different prescriptions or values incorporated into these appliances. The brackets are continually being modified and updated and the choice of which particular edgewise bracket system to use is further complicated by the fact they are available in two different bracket slot dimensions.

CONTROL OF TOOTH MOVEMENT USING THE EDGEWISE BRACKET

To control the tooth in all three dimensions the many different edgewise bracket designs rely upon the interaction of the archwire in the bracket slot. Tooth movements can be tipping, bodily or a combination of the two.

First order tooth movements

First order tooth movements refer to the in/out or bucco-lingual positioning of the teeth within the arch. The standard edgewise brackets have a set bracket thickness which results in the distance from the labial surface of the tooth to the base of the archwire slot being the same for all teeth. To allow for the differing bucco-lingual positioning for each tooth within the arch, small horizontal compensation bends or 'offsets' and 'insets' must be placed in the archwire. Offsets are often placed for the canines and molars with insets for the upper lateral incisors. To maintain the desired in/out positioning of the teeth following the use of initial aligning archwires, these bends must be reproduced in each new archwire used.

The preadjusted edgewise brackets have a different predetermined bracket thickness or height for each tooth within the arch. This alters the distance from the labial surface of the tooth to the base of the archwire slot which allows differing bucco-lingual positioning of the teeth to occur when a plain archwire is inserted. The upper lateral incisor bracket height is usually the greatest, to achieve an inset, while the canine usually is the least to achieve an offset. Various molar offsets are also available. This effectively reduces the need for in/out archwire bends when using the preadjusted brackets (Fig. 1).

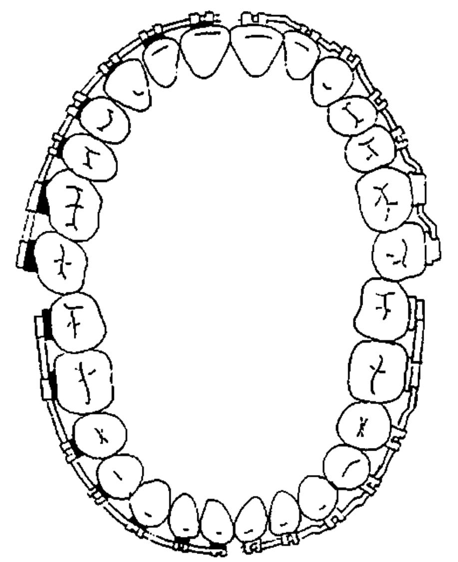


Fig. 1. A comparison between the "Preadjusted" and the "Standard" edgewise brackets in controlling first order tooth movements.

Preadjusted - Differing bracket heights compensate for the various in/out tooth positions within the arch when a plain archwire is placed.

Standard - Various "insets" and "offsets" bends are required in the archwire to compensate for the in/out tooth position within the arch. Second order tooth movements

Second order tooth movements

Second order tooth movements refers to the mesio-distal tip or angulation of the tooth within the arch. In all edgewise brackets the amount of mesio-distal tip is determined by the angle at which the archwire passes through the vertical wings or sides of the slot. When viewed from the labial standard edgewise brackets have the archwire slot perpendicular to the long axis of the tooth and the vertical sides or wings of the slot parallel to the long axis. To obtain the correct mesio-distal tip for each tooth small vertical or angulation bends must be placed in the archwire. These are sometimes termed 'aesthetic' or 'artistic' archwire bends and are most common in the anterior segment as correct angulation of these teeth is critical for good aesthetics. Following the use of the initial aligning archwires these second order bends must be reproduced in each new archwire used to maintain the desired tooth angulation.

In comparison, the preadjusted edgewise brackets have differing predetermined archwire slot angulations which alters the angle of the archwire slot to the long axis for each tooth. This effectively reduces the need for angulation bends, although it is dependent upon the accuracy of the initial bracket placement (Fig. 2).

Third order tooth movements

Third order tooth movements refer to the torque or axial inclination of the teeth within the arch. This is achieved by the use of rectangular archwires which engage the edgewise slot to produce bodily tooth movements in the bucco-lingual plane. Standard edgewise brackets have the angle of the slot base parallel to the labial surface of the tooth and this is the same for all teeth. To obtain the correct inclination of each different tooth, the rectangular wire must be twisted or torqued in the horizontal plane. Specially milled torquing turrets with differing angular sleeves are used when fabricating the anterior segment of the rectangular archwires. The amount of torque placed into the anterior arch is determined by the angle of the milled sleeve selected from the torquing turret. To obtain individual torquing bends in the archwire, pliers which have parallel beaks are used. Once the correct inclinations have been achieved, third order archwire bends need to be reproduced whenever a new rectangular archwire is placed.

Preadjusted edgewise brackets have 'built-in' predetermined slot inclinations in relation to the labial tooth surface. These are different for each tooth and may be incorporated in the face of the bracket or in the bracket base. Torque in the bracket base

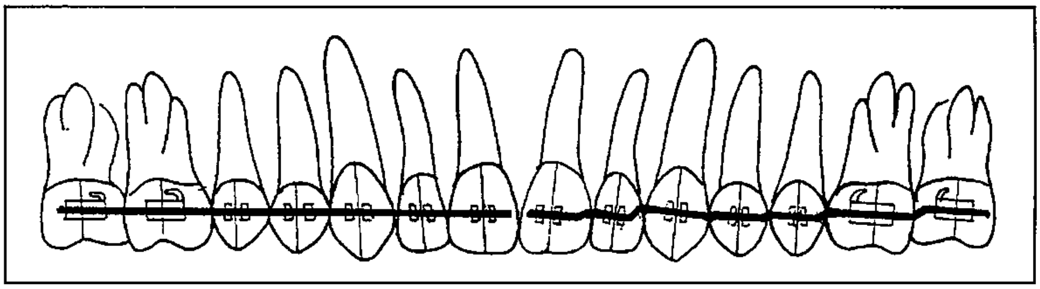


Fig. 2. A comparison between the "Standard" and the "Preadjusted" edgewise brackets in controlling second order tooth movements.

Preadjusted - Differing archwire slot angulations alter the angle of the slot to the long axis of each tooth.

Standard - Second order archwire bends are required to achieve the desired tip or angulation for each tooth.

has an advantage as the height of the bracket slot is constant for each tooth. Brackets which have torque in the face will have altered slot height positions which vary proportionally to the amount of torque placed in the bracket. An accurate bracket fit to the labial surface of the tooth is also important to allow the torque to be transferred to the tooth, without any potential alterations to these values. The need for archwire manipulation to achieve third order tooth movements is considerably reduced when using the preadjusted appliances. However, archwire manipulation for individual torquing movements is often required to fully treat most cases (Fig. 3).

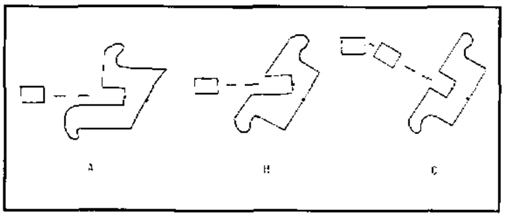


Fig. 3. A comparison between the "Standard" and the "Preadjusted" edgewise brackets in controlling third order tooth movements.

A - Preadjusted bracket with torque placed in the base of the bracket. The slot height is constant for each bracket regardless of the amount of torque placed in the bracket. The occlusio-gingival curve to the bracket base ensures accurate bracket fit.

B - Preadjusted bracket with torque placed in the face of the bracket. The slot height positions will vary with the amount of torque placed in the bracket. Some preadjusted brackets do not have bases that are curved occlusio-gingivally.

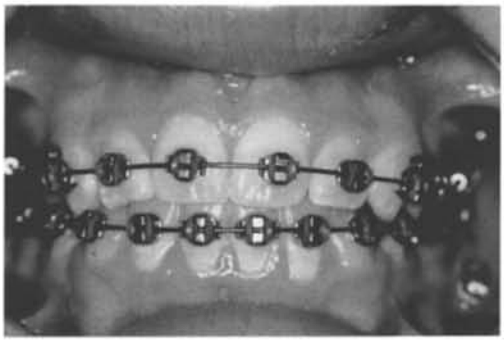
C - Standard bracket. Torque must be added to the rectangular archwire to achieve the desired third order tooth movements.

Rotational control

The degree of rotational control with edgewise brackets is dependent upon the mesiodistal width of the bracket. The greater the width the greater the rotational control. This is achieved however at the expense of reducing the inter-bracket distance which has implications during initial alignment, space closure utilising archwire loops and final detailing of the occlusion. Some bracket systems have attempted to overcome this problem by maintaining a narrow bracket slot but incorporating mesial and distal bracket extensions, as with the Lewis and Lang bracket or shaping the tie wings to extend mesio-distally further than the bracket slot, as with the Unitwin bracket (Fig. 4). Some preadjusted appliances have anti-rotations built into the brackets which can be helpful in extraction cases. The preadjusted appliance also incorporates various molar offsets and distal rotations into their molar tubes. This results in the molars taking up a predetermined bucco-lingual position within the arch and relies less upon the placement of first order archwire bends which must be routinely used when the standard edgewise brackets are placed.

History

When Angle (1928) first introduced his Edgewise appliance following experimentation with earlier appliance designs he described it as the "Latest and Best in Orthodontic Mechanism". The appliance was designed for non-extraction treatment which was Angle's philosophy based upon the desire to position teeth in their ideal arrangement and allow the jaws and arch forms to grow and accommodate the new tooth positions. With the reorientated horizontal archwire slot a round archwire could be used for initial expansion by labial or buccal crown tipping. A rectangular wire could then be inserted to torque the roots labially or buccally stimulating bone growth. The original appliance was designed to make use of the existing archwire materials at that time, namely gold, which had a reasonable range of action particularly for the third order tooth movements.



A

B

C

Fig. 4. Three different Bracket designs and rotational control.

A - The Lewis bracket with a narrow bracket slot increases the interbracket distance but gains rotational control with mesial and distal wing extensions.

B - The Unitwin bracket has a narrow bracket slot which increases the interbracket distance and increases rotational control with mesial and distal tie wing extensions.

C - The siamese or twin bracket with a wider bracket slot for rotational control but with a reduced interbracket distance.

Bracket slot size

The original edgewise appliance had a bracket slot dimension of 0.022" (0.55mm) wide by 0.028" deep. This was designed to accommodate gold archwires of the same width. As knowledge of metallurgy increased and following the introduction of the first stainless steel archwires in the late 1920's, gold archwires were replaced by the stiffer stainless steel wires. It became obvious that full sized stainless steel wires were of limited use due to their short range of action, particularly for third order tooth movements. Torquing and finishing bends were extremely restrictive and the force levels applied to the teeth were excessively high. Smaller dimension stainless steel archwires could be used to improve the range of torsion, but because the archwires were undersized effective torque control was lost.

The development of the 0.018" (0.45mm) wide archwire slot was in response to the above limitations imposed by the change of archwire materials. By reducing the rectangular archwire size to a maximum of 0.018" x 0.025", the range and force levels delivered were more acceptable and more closely resembled the properties of the original appliance.

With the introduction of the TMA® (Ormco, Glendora, California, USA) nickel titanium and heat sensitive nickel titanium archwires the limitations of the original 0.022" slot have largely been overcome. These archwires have an increased range of action with lower force levels for a given deflection. Some manufacturers have increased the slot depth from Angle's original 0.028" to 0.030" to allow for easier engagement of larger wires as well as piggy back or auxiliary wires which can be used in combination with the main archwire.

Both the 0.022" and the 0.018" appliances are used world wide, although Matasa (1992) suggests the 0.022" brackets are more common in North America while the 0.018" brackets are more common in Europe. This may be a reflection of the different clinical teachings as well as the different market share of the various bracket manufacturers.

Bracket width

Angle's original appliance consisted of narrow single brackets placed on the centre of each tooth. To gain extra rotational control he incorporated eyelets at the corner of his bands. Swain developed the Siamese bracket or Twin bracket where two narrow single brackets were placed on the same tooth joined by a common base. At that time these brackets were welded to bands. Today they are bonded to the teeth with both single and twin brackets used widely, often in combination.

Bracket construction

Angle's original brackets were welded to bands which were individually pinched and soldered for each tooth. Today the bands are prewelded and since the introduction of acid etched composite (Buonocore 1954), and more recently light cured glass-ionomer cements (Fricker 1995), most anterior and premolar brackets are now bonded directly to the labial tooth surfaces. Various grades of stainless steel are used in the manufacture of these brackets which can be either cast or milled. Due to their reduced bulk, higher grades of stainless steel are generally used for the miniaturised brackets to increase their strength and to resist slot distortion from normal masticatory loading.

Polycarbonate or plastic edgewise brackets became available in the 1960's in an attempt to improve the aesthetics of fixed appliances. They had several limitations which include gradual discolouration, bond failure, increased archwire friction as well as lack of slot rigidity which does not allow for full expression of torque. Recent modifications have included the introduction of a ceramic reinforced plastic to limit discolouration and increase strength, and the incorporation of a metal slot within the plastic to increase the ability to fully express torque.

In the late 1980's alumina or ceramic edgewise brackets became available in either mono or polycrystalline form (Fig. 5). These brackets offer considerable advantages over the plastic brackets as they are colour stable and have a rigid archwire slot. Disadvantages include enamel wear of upper anteriors when used in the lower arch in deep bite cases (Viazis *et al.*, 1990), increased archwire friction, as well as possible tie wing and slot fracture due to their brittleness and low fracture toughness. It is, however, the removal of the ceramic brackets that has been of significant concern. Ceramic brackets rely upon either the use of a silane coupling agent and/or mechanical retention for their bond strength. With the earlier brackets using the silane agent the possibility of enamel cracks or loss of sections of enamel were reported during debonding (Swartz 1988). Subsequent modifications to bracket design as well as the introduction of different debonding tools has now largely addressed this problem (Winchester 1993). The recent incorporation of a metal slot within the ceramic bracket has also largely overcome any frictional problems.

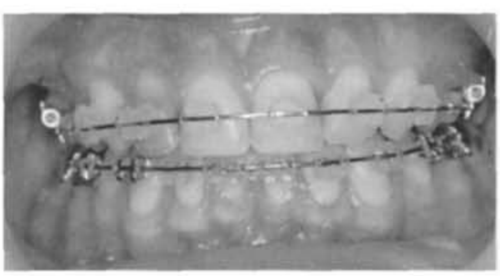


Fig. 5. Ceramic brackets on the upper anteriors with polycarbonate brackets on the lower anteriors.

PREADJUSTED EDGEWISE OR STRAIGHT WIRE APPLIANCE

History

The concept of reducing the need for repeatedly placing archwire bends was first advocated by Angle (1928). He suggested pre-angulating the bracket on the posterior bands to reduce the need for second order archwire bends for these teeth. Holdway (1952) suggested angulating all brackets, anterior and posterior, leading to easier archwire fabrication. Jarabak and Fizzell (1963) incorporated 'built-in' second and third order tooth movements into the Edgewise bracket. Technology at that time prevented the incorporation of first order tooth movements into their brackets. Although the concept of a fully preadjusted Edgewise appliance had been earlier conceived by Steiner (1933) it was not until the late 1960's that Andrews began to develop a bracket system with first, second and third order tooth movements incorporated into their design. Andrews (1975) stated correctly positioned bracket slots should be passive to an unbent rectangular archwire when the teeth are properly aligned. The advantages of a plain arch form without bends, used in conjunction with the fully preadjusted brackets include; ease of archwire fabrication, less chair-side time, efficiency of direct tooth movement with minimal jiggling of the teeth following archwire changes and greater patient comfort.

Following the development of the Andrews' Straight Wire Appliance many other manufacturers with the help of various clinicians have designed and produced variations of the original fully preadjusted appliance. There is a large variation in prescription values between the various preadjusted appliances, particularly in the second and third order tooth movements (Table 1 and 2). Inclination (torque) and angulation (tip) are expressed as positive or negative values depending upon the relationship of the occlusal and gingival portion of the crown. This is in reference to a line perpendicular to the occlusal plane and tangent to the middle of the labial crown (Andrews 1972).

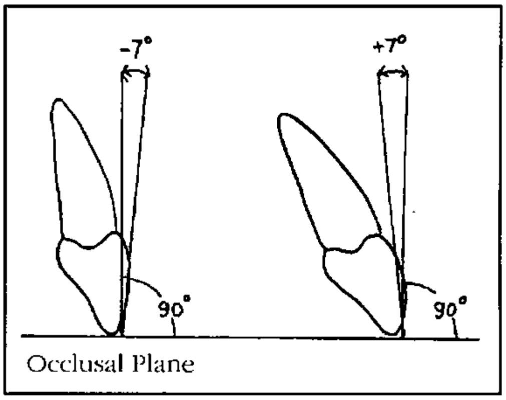


Fig. 6. Crown inclination or torque
Labio-lingual view of an upper central incisor. Positive torque values indicate the gingival portion of the crown is lingual to the incisal portion. Negative values indicate the gingival portion of the crown is labial to the incisal portion.

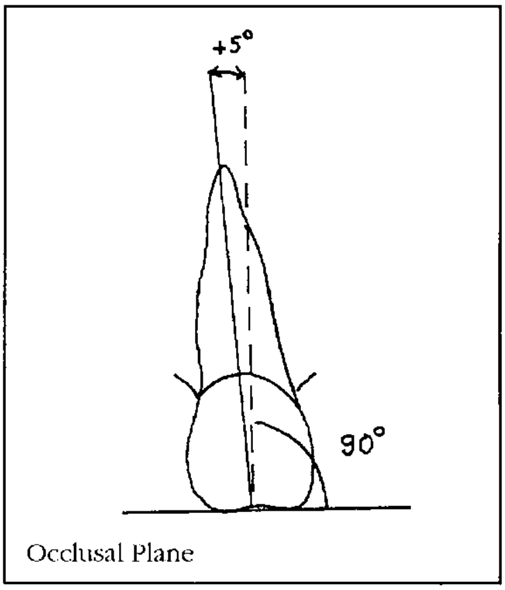


Fig. 7. Crown angulation or tip
Mesio-distal view of an upper central incisor. Positive angulation values indicate that the gingival portion of the crown is distal to the incisal portion.

Table 1 - Angulation Values (degrees) of some Pre-Adjusted Appliances

Tooth	Andrews SWA				Roth SWA	MBT Appliance Values	Alexander Vari-Simplex	Ricketts Bio-Progressive	Hilgers Linear Dynamic		Hilgers Bios High Torque	Root level Anchorage		Orthos System Std	Orthos Asian Profile
	Std	E1	E2	E3						E			E		
Upper															
1	+5				+5	+4	+3	0	+5		+5	+4		+5	+4
2	9				+9	+8	+6	+8	+8		+9	+7		+9	+6
3	+11	+13	+14	+15	+13	+8	+6	+5	+7	+10	+10	0		+10	+8
4	+2	+4	+5	+6	0	0	0	0	0	-5	0	0		0	+4
5	+2	0	-1	-2	0	0	0	0	0	-5	0	0		+4	+6
6	+5	+3	+2	+1	0	0	0	0	0		0	-15		0	0
7	+5	+3	+2	+1	0	0	0	0	0		0	2		0	0
Lower															
1	+2				+2	0	+2	0	0		+2	+2		+2	0
2	+2				+2	0	+2	0	0		+4	+2		+4	0
3	+5	+7	+8	+9	+7	+3	+6	+5	+5	+9	+6	-4		+6	+2
4	+2	+4	+5	+6	1	+2	0	0	0		+3	-4		+3	+3
5	+2	0	-1	-2	-1	+2	0	0	0		+3	-4	-6	+3	+6
6	+2	0	-1	-2	-1	0	-6	+5	-5		0	-6	-10	0	0
7	+2	0	-1	-2	-1	0	-6	+5	-5		0	-10	-15	0	0

Table 2 - Inclination Values (degrees) of some Pre-Adjusted Appliances

Tooth	Andrews SWA				Roth SWA	MBT Appliance Values	Alexander Vari-Simplex	Ricketts Bio-Progressive	Hilgers Linear Dynamic	Hilgers Bios High Torque	Root level Anchorage Std	Orthos System Profile	Orthos Asian
	Std	S1	S2	E1									
Upper													
1	+7	+12			+12	+17	+14	+22	+22	+22	+15	+15	+11
2	+3	+8			+8	+10	+7	+14	+14	+14	+7	+9	+9
3	-7				-2	-7	-3	+7	+7	+7	0	-3	0
4	-7				-7	-7	-7	0	-7	-6	-7	-6	-2
5	-7				-7	-7	-7	0	-7	-8	-7	-8	-3
6	-9			-13	-14	-14	-10	0	-10	-10	-10	-10	-10
7	-9			-13	-14	-14	-10	0	-10	-10	-10	-10	-10
Lower													
1	-1	+4	-6		-1	-6	-5	0	-1	-5	0	-5	+3
2	-1	+4	-6		-1	-6	-5	0	-1	-5	0	-5	+3
3	-11				-11	-6	-7	+7	+7	+7	0	-6	-2
4	-17				-17	-12	-11	0	-11	-7	-11	-7	-8
5	-22				-22	-17	-17	0	-22	-17	-11	-9	-8
6	-30				-30	-20	-22	0	-27	-27	-22	-10	-10
7	-35				-30	-10	0	0	-27	-27	-25	-10	-10

The amount of torque available in the various appliance prescriptions varies more than any other feature. Several factors appear to be important when assessing the different torque values used.

1. Torque values may vary due to differences in the recommended bracket position on the labial surface of the tooth. Andrew's bracket position for an upper canine is placed gingival to that of Roth's and this will alter the amount of torque that may be expressed. This is particularly important with teeth that have curved labial surfaces.
2. Torque values may vary due to the different types of mechanics used and the desire for any over corrections recommended in the final tooth positions.
3. Differences between extraction and non-extraction treatment can also influence the choice of torque values as can allowances for different skeletal patterns.
4. Torque values may vary due to differences in the various archwire sizes recommended in relation to the bracket slot dimension. Creekmore (1979), Dallinger (1978) and Sebanc et al (1984) have all demonstrated a considerable degree of torque control can be lost due to the size differences between the archwire and the bracket slot dimensions.
5. Differences in torque values may also be a reflection of the different methods used by the various appliance designers to obtain their average values, which they have then used to incorporate into their brackets. Some designers have used either treated occlusions or untreated normal occlusions, while others have used a combination of both.

Angulation and rotational values also differ as do the degree of molar offsets. This is often a reflection of the final treatment position recommended by the designers of the various appliances as well as whether extractions are required. Facial prominence or in/out values vary marginally and are described as the thickness of the bracket bases.

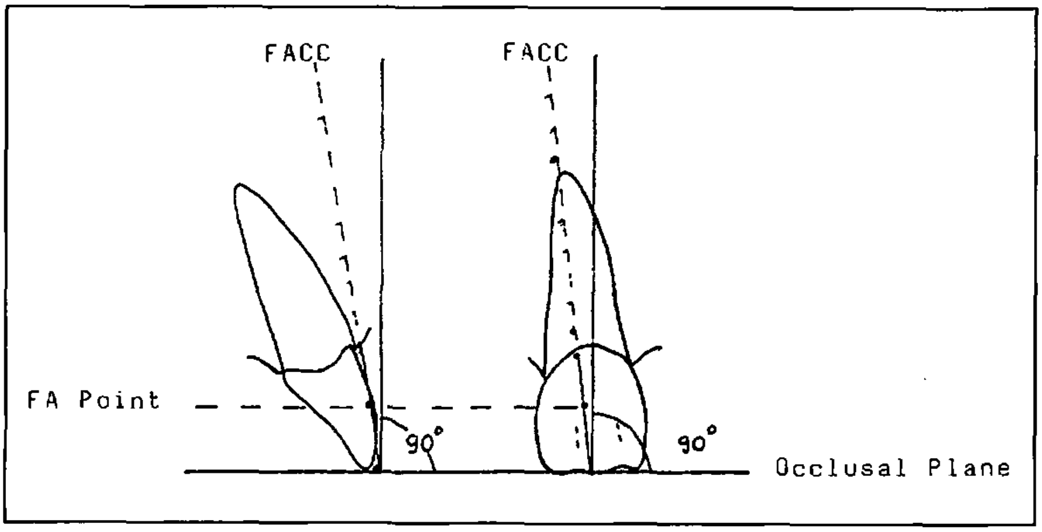


Fig. 8. The facial axis of the clinical crown (FACC) and the FA point

ANDREWS STRAIGHT WIRE APPLIANCE

Andrews (1969) obtained the values for his appliance from his study of 120 models taken from individuals described as having normal occlusions and who had never received orthodontic treatment. These models were studied to establish the position and relationship of the crowns. Six significant characteristics were found to be consistent in all of the models and Andrews (1972) termed these the 'Six Keys To Normal Occlusion'. To analyse these models and obtain data for his appliance he chose two anatomical landmarks which were applicable to all crowns. These served as a reference line, the Facial Axis Of the Clinical Crown (FACC), and a reference point, the Facial Axis (FA). Andrews originally termed these landmarks the Long Axis of the Clinical Crown (LACC) and the Long Axis (LA) point and are the basis of his bracket locations (Fig. 8).

Andrews (1976) chose the FACC and FA point for his bracket positions because he considered them to be scientifically reliable, precise, dependable and re-locatable. They are less likely to be altered by trauma or wear and they offered a more consistent bracket location than the widely practised arbitrary measurements taken from the incisal or cusp tip. By using acrylic templates and a protractor with an adjustable read-out arm, Andrews obtained mean prescription values which he incorporated into his Standard Appliance. These brackets are most suitable for Class I, non extraction cases. Anti-tip and anti-rotation values were designed for extraction cases, the values depending upon the amount of tooth translation required. Different values are also available for differing skeletal patterns, particularly torque to the anteriors. Despite these different bracket prescriptions, Berman (1988) suggests it is not uncommon to use the Standard prescription to treat virtually all cases allowing for minor archwire adjustments.

Roth Straight Wire Appliance

Roth (1987) developed his prescription values from those of Andrews but allowed for over-correction and finishing treated cases without resorting to placing compensating curve of Spee in the archwires. Most notable is the increased torque in the upper anteriors as well as increased tip to the upper canines. Roth states his values also reduces the need to deal with the inventory concerns of multiple appliance prescriptions.

MBT Versatile and Appliance

McLaughlin, Bennett and Trevisi (1997) also developed their appliance prescription values from those of Andrews but increased palatal root torque in the upper incisors, labial root torque in the lower incisors and reduced lingual crown torque in the lower buccal segments. Canine and incisor tip was also reduced as was the tip to the upper molars. McLaughlin, Bennett and Trevisi claim their modifications to Andrews' values are required to improve both clinical control and treatment efficiency.

Alexander Vari-Simplex Appliance

Alexander (1983) values were obtained by measuring the archwire bends he routinely placed in his finishing rectangular archwires in 'well treated' cases using standard edgewise brackets. These values were then modified with clinical evaluation and have three main differences when compared with other prescriptions. Alexander (1986) states the upper canines have - 3 degrees torque in order to eliminate the need for further adjusting the canine's torque later in treatment. A large portion of his cases are treated non-extraction and the lower incisors are torqued at -5 degrees, to counteract the tendency of these teeth to tip forward during treatment. Alexander uses Omega loops mesial to the lower second molars and these attachments

have a zero torque value. This allows torque to be placed into the wire when the Omega loop is tipped away from the gingiva for ease of ligation. Alexander recommends bracket heights that are measured from the incisal edge, allowing some adjustments for open bite cases and variations in crown size.

Ricketts Bioprogressive Appliance

Ricketts (1976) designed the 'Bioprogressive Appliance' with values obtained from a series of studies on normal occlusions from dried skulls as well as treated patients. These were modified with clinical evaluation and differ from other prescriptions in the increased torque to the upper anterior teeth, as well as +7 degrees torque for the upper canines. Ricketts recommends the centre of the clinical crown for his bracket placement, but variations in bracket height are suggested for deep bite or open bite cases.

Hilgers Linear Dynamic Appliance

Hilgers (1987) describes his appliance as a continuation of the principles of the Bioprogressive Appliance, but with torque added to the posterior segments, minor alterations to in/out and differences for extraction and non-extraction series brackets. Hilgers has made further modifications in his Bios High Torque Appliance where there are high torque values added to the upper anteriors allowing for earlier torque control with out the use of full sized edgewise archwires. Hilgers recommended bracket location is based on measurements taken from the incisal edge.

Andreiko (1994) describes the Orthos Appliance as a coordinated system of brackets, tubes and archwires. The appliance values were obtained from a computer analysis of 100 cases set to an ideal occlusion. Values were averaged and refined to account for functional occlusion requirements. An Asian Profile prescription of this appliance has also been developed with allowances for altered tooth morphology and Asian anatomical norms.

Root Level Anchorage Appliance

Root (1987) described this appliance as a continuation of the Tweed treatment philosophy, but utilising preadjusted brackets. Differences in tip and torque values are related to the concept of anchorage preparation particularly in the lower arch with increased distal crown tip. Root recommends the use of standard bracket heights measured from the incisal edges.

ASSUMPTIONS OF THE PREADJUSTED APPLIANCES:

All preadjusted appliances are marketed as precision attachments that allow the clinician a high degree of precise tooth control and to improve the functional positioning of the teeth with simplified archwire manipulation. The accuracy of any preadjusted appliance assumes there is accurate and consistent bracket placement as well as a good bracket fit against the labial tooth surface. They also assume the general tooth morphology is sufficiently consistent to allow the expression of built-in values, resulting in tooth positions that are characteristic of good occlusions and such tooth positions will be appropriate for most patients. They further assume there will be enough flexibility in the three dimensional orientation of the teeth, in good occlusions, to accommodate any variation in the size and form of the teeth. The precision of the appliance is also dependent upon the interaction of the archwire in the bracket slot to allow full expression of the built-in values of the brackets for each tooth.

Bracket location

Bracket location is a critical requirement for the successful use of the preadjusted brackets. The clinician must have the ability to identify the anatomical landmarks that are

essential for the recommended bracket location and having done this, to execute the actual bracket placement consistently and accurately for each tooth. Bracket placement jigs or aids can be used and often brackets have scribe lines to help orientate the long axis correctly. Fowler (1990) demonstrated clinicians of varying degrees of orthodontic experience were reasonably accurate in locating Andrews FA point but variations were found in the angulation of the FACC. Taylor and Cook (1992) found clinicians judgement in placing preadjusted brackets were less consistent for slot angulation than vertical bracket position. Incorrect bracket angulation may allow root approximation to occur before crown contact and hence, prevent full space closure in extraction cases. It may also alter the space requirements for crown alignment in the arch. Meyer and Nelson (1978) demonstrated variations in crown torque as well as in/out can also occur with incorrect vertical placement of the brackets. Read (1987) suggested indirect bonding is preferable to direct bonding as it allows more precise bracket positioning, although Aguirre *et al.*, (1982) found only small differences when comparing the two techniques.

Bracket fit

Bracket fit has an important role in allowing the built-in values of the bracket to be transferred accurately to the tooth when the various archwires are engaged in the slot. Bracket fit depends upon the configuration of the bracket base, the thickness of the adhesive and the consistency of the facial contour of the teeth. The facial contour at the bracket sites are reasonably consistent (Wheeler 1965) although variations can occur in some individuals. Brackets with bases that are curved occlusio-gingivally and mesio-distally will limit any potential alteration in the built-in torque due to poor bracket fit.

Archwire/brackets interaction

Dellinger (1978) calculated the deviation angle as degrees of freedom between the various size archwires and both the 0.022" and 0.018" bracket slots. He demonstrated a large range of theoretical deviation angles which were further increased when manufacturing tolerances of error for the archwire dimensions were taken into consideration. Creekmore (1979) calculated a deviation angle of +/-10.5 degrees for an 0.019 x 0.025" archwire in an 0.022 bracket slot and +/-4.5 degrees for an 0.017 x 0.025" archwire in an 0.018" slot. Sebanck *et al.*, (1984) assessed the variability of effective torque as a function of the edge bevel on various rectangular wires and suggested both Creekmore and Dellinger had under estimated the true deviation angles. As the deviation angle increases the amount of torque that is transferred from the bracket to the tooth is reduced.

The clinical importance however, of such large deviation angles as suggested above, may be considerably less when various clinical procedures are considered. Procedures such as, space closure, overjet reduction, placement of accentuated curves or reverse curves of Spee as well as variations in slot alignment, will all increase the contact between the archwire and bracket slot. This will reduce the deviation angle and effectively allow for a more accurate expression of the various built-in torque values.

TREATMENT MECHANICS WITH THE PREADJUSTED APPLIANCE

There are many different treatment techniques and biomechanics used with the edgewise appliance reflecting its extreme versatility. These variations are due to differences in the clinical training and treatment philosophy as well as features of each individual malocclusion. The treatment mechanics listed below are often used with the fully

preadjusted appliance and although these are dealt with separately and in a certain order, they are all inter-related.

Levelling and alignment

Light multi-strand or nickel titanium aligning archwires are used to activate tooth movement. Severe vertical or labio-lingual positioning between adjacent teeth may require partial engagement of the archwire initially. For extremely crowded or displaced teeth, no engagement is made until space has been created (Berman *et al.*, 1986).

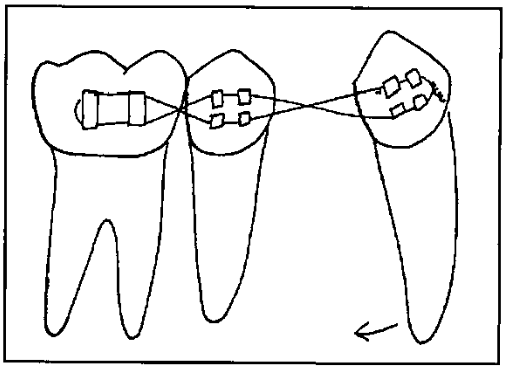


Fig. 9. "Lace back" ligature
A 0.010" stainless steel ligature is figure '8' tied from the molar to the canine. This helps prevent the canine crown from tipping mesially during uprighting and encourages the root to move distally.

The most dramatic initial effect of the first aligning wires in the preadjusted brackets results from the angulation of the canine brackets. There is a tendency for the canine crown to move mesially and to also extrude the incisors, particularly if the canine is distally angulated pretreatment. The canine crowns should be held back to prevent this crown movement and this is best achieved by the use of a 0.010" 'lace-back' stainless steel ligature (Robinson 1989). This encourages the canine root to move distally as opposed to the crown mesially as the tooth's angulation is corrected (Fig. 9). To minimise the forward movement of the anteriors during levelling and alignment the distal portion of the archwire should be bent hard behind the buccal tube of the last molar. Full alignment and levelling is achieved by the progressive increase of archwire size and stiffness.

Anchorage control

There is a tendency for the anterior segments to move forward during the initial levelling and aligning stage of treatment. Consideration for anchorage control beyond the placement of lace-backs and distal archwire bends should be made. This will depend upon the overall anchorage requirements of each individual case. This may involve the use of molar tie backs, palatal or lingual arches, headgear and indirectly Class III elastics. Because these measures may be needed during the initial stages of treatment it has been stated by some that preadjusted appliances are 'anchorage demanding'. Andrews (1989) however has stated most orthodontic results he evaluated were undertreated and to achieve the same treatment result using other appliance systems would require the same amount of anchorage control. Bennett and McLaughlin (1993) suggest while the total anchorage control is the same for a given case regardless of the type of appliance used, the anchorage requirements at the beginning of treatment are generally greater with the preadjusted brackets. Frequently the need for anchorage control at the end of treatment becomes less when compared with the standard edgewise brackets as the correct angulations have been achieved during the earlier stages of treatment.

Overbite and overjet reduction

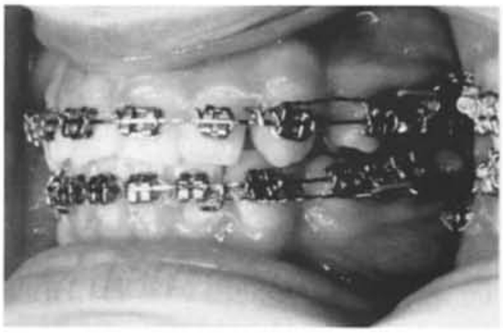
There is often some tendency for the overbite to deepen temporarily during the initial alignment stage of the treatment due to the angulation of the canine bracket. As the canines assume their normal angulation, the anterior segments are levelled and the overbite reduces. To achieve full overbite correction particularly in deep bite

cases, reverse and accentuated curves of Spee are often needed in the archwires. Banding the second molars also helps in the intrusion of the anteriors and elevation of premolars to level the arches. In extremely deep bite cases use of anterior bite plates, anterior high pull headgear or auxiliary intrusion archwires may also be required. Bioprogressive mechanics advocated by Ricketts (1976) uses sectional archwires which involve placing separate wires for the buccal and anterior segments and the use of various auxiliary intrusion arches. Overjet reduction can be carried out with 'en masse' movement of the upper anterior segments with the normal considerations for anchorage control and molar positioning. Some clinicians however retract the canines separately prior to retracting the remaining anterior segments.

Space closure

The two main methods used to close spaces within the dental arch are looped mechanics and sliding mechanics. Looped mechanics involves the fabrication of a closing loop within the archwire. The archwire remains static within the bracket slots when the closing loop is activated. This has the distinct advantage that there are no frictional forces to overcome from the archwire/bracket interaction. The type of wire, the diameter as well as the length of wire incorporated into the loop will all effect its range of action as well as the force levels applied. Problems of food traps and gingival impingement often limit the length of wire incorporated into the loop. However, due to the closing action of the loop, tipping of the teeth adjacent to the space can occur. There are many different loop designs used to compensate for this undesirable reaction of the closing loop and placing the loop at a distance from the space will also tend to limit any tipping (Fig. 10). If sectional looped mechanics are used anti-tipping and anti-rotational archwire bends should also be incorporated.

A



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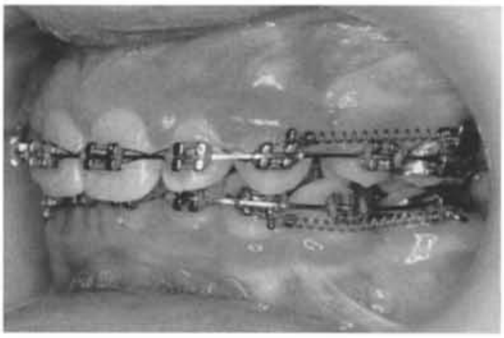


C

Fig. 10. Space closure mechanics

A - Looped archwire to close upper first premolar space. Note the use of a narrow bracket with an increased interbracket distance to allow for a greater range of activation with the closing loop.

B - Sliding mechanics using an elastic force to close both upper and lower first premolar spaces.

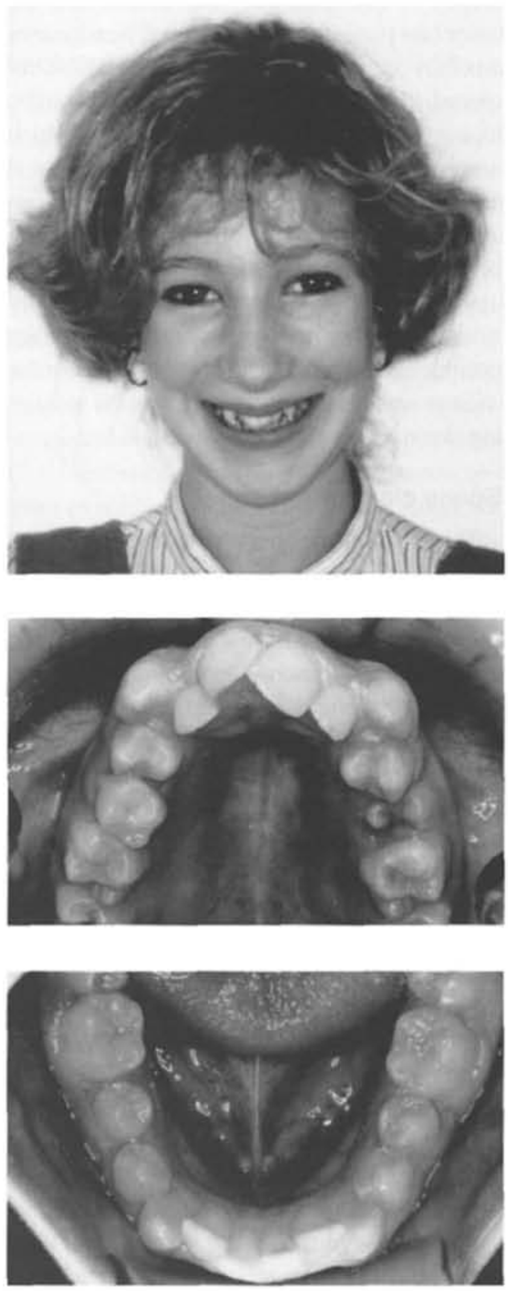
C - Sliding mechanics using closing springs to close the upper first and lower second premolar spaces.

Sliding mechanics involves the use of a force, either elastic or closing spring, which when activated, slides the teeth along the archwire. The archwires must be of sufficient size and stiffness to allow the teeth to slide along the wire without allowing the teeth to tip and bind to the wire. There must be, however, some degree of freedom between the archwire and the bracket slot to allow the teeth to slide and to limit the frictional resistance of the archwire/bracket slot interface. Often a 0.017" x 0.025" stainless steel archwire is used with the 0.018" bracket slot and a 0.019" x 0.025" archwire used with the 0.022" bracket slot. The latter allows better sliding mechanics because the archwires have greater rigidity but also have adequate clearance to help reduce frictional resistance to movement. The surface qualities of the bracket slot and the archwire also influences the amount of frictional resistance. Keith, Jones and Davies (1993) found greater frictional resistance with ceramic brackets when compared with metal brackets using stainless steel archwires. Kaplia *et al.*, (1990) suggest that titanium alloy archwires produced more friction due to surface roughness when compared with stainless steel archwires.

Finishing

The great advantage of the preadjusted brackets is it allows for greater control of the 3 dimensional positioning of each tooth without incorporating time consuming first, second and third order archwire bends. To achieve final detailing however, some archwire bends are necessary to compensate for variations in bracket placement, anatomical variations in crown and root morphology as well as to achieve any over corrections that may be desired. It may be necessary to change down to a smaller archwire to correct any minor discrepancies.

The following case helps to demonstrate some of the above mechanics that may be used with a fully preadjusted edgewise appliance (Fig. 11).



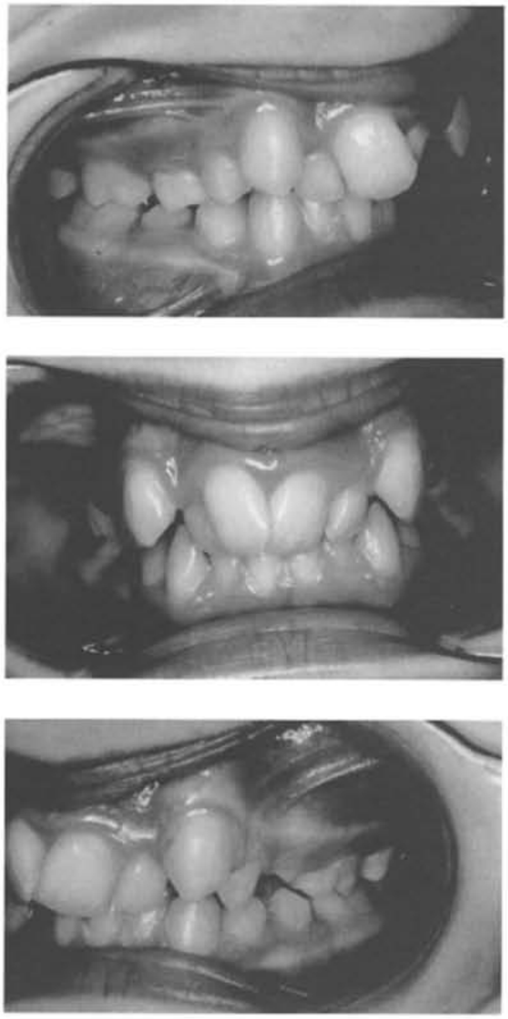


Fig. 11. A - Pretreatment: Class II Division 1 case with severe crowding, an increased overjet and overbite. Four first premolars were extracted and 0.022 preadjusted edgewise brackets placed (Andrews' values).

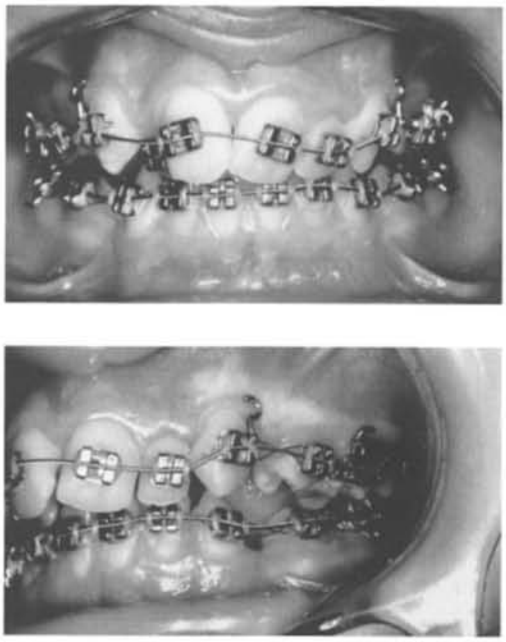
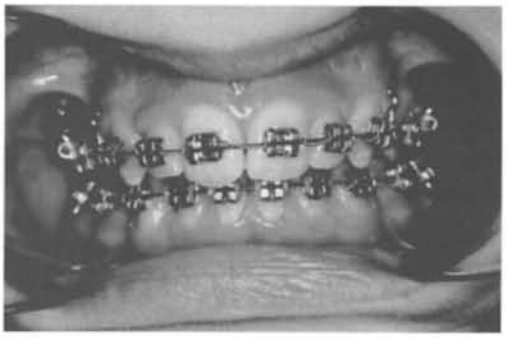


Fig. 11. B - Initial aligning wires partially engaged. Note lace backs from the molars to the canine brackets.



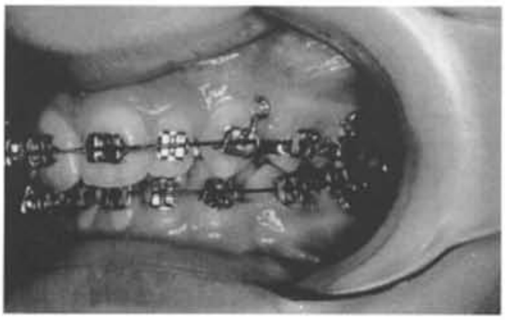


Fig. 11. C - 0.020 stainless steel archwires following alignment and some levelling.

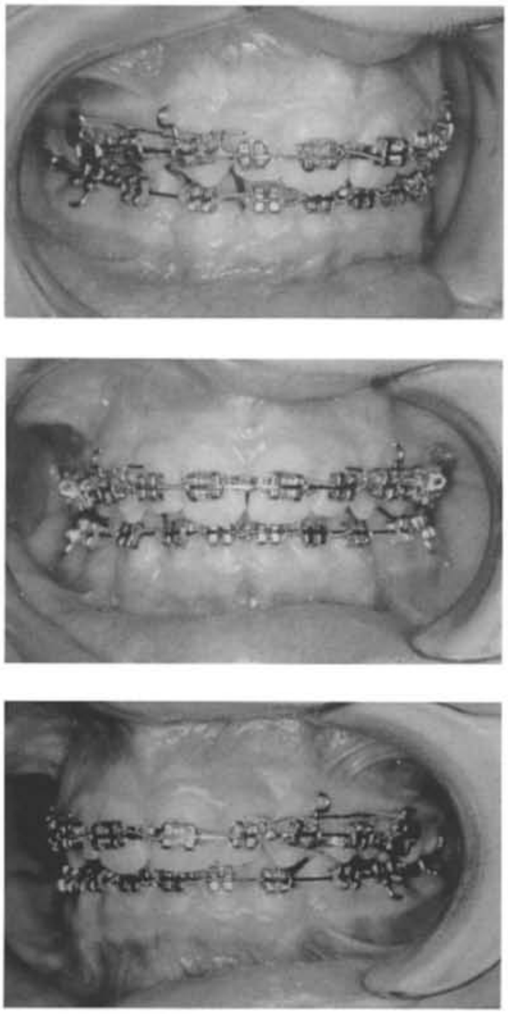
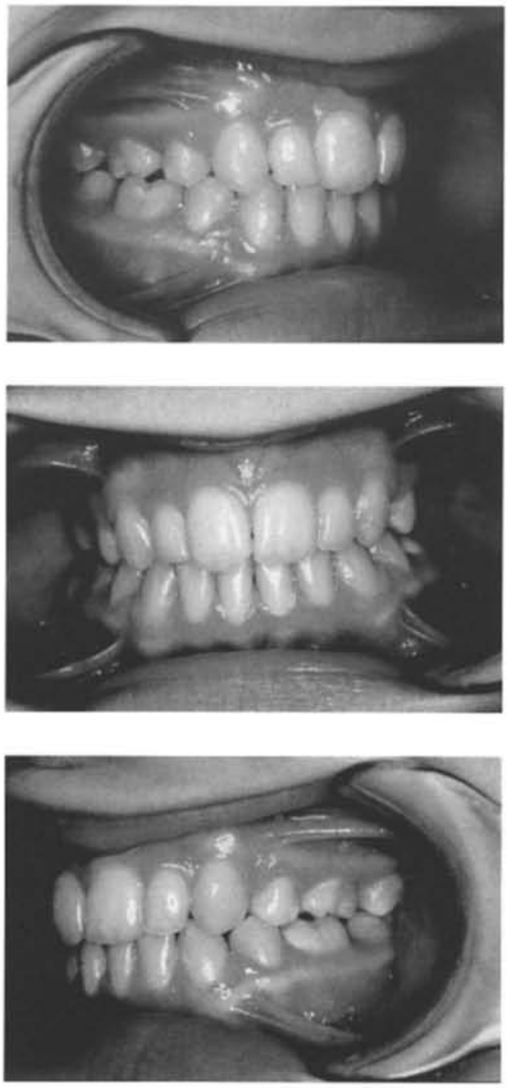


Fig. 11. D - 0.019 x 0.025 stainless steel archwires with sliding space closing mechanics



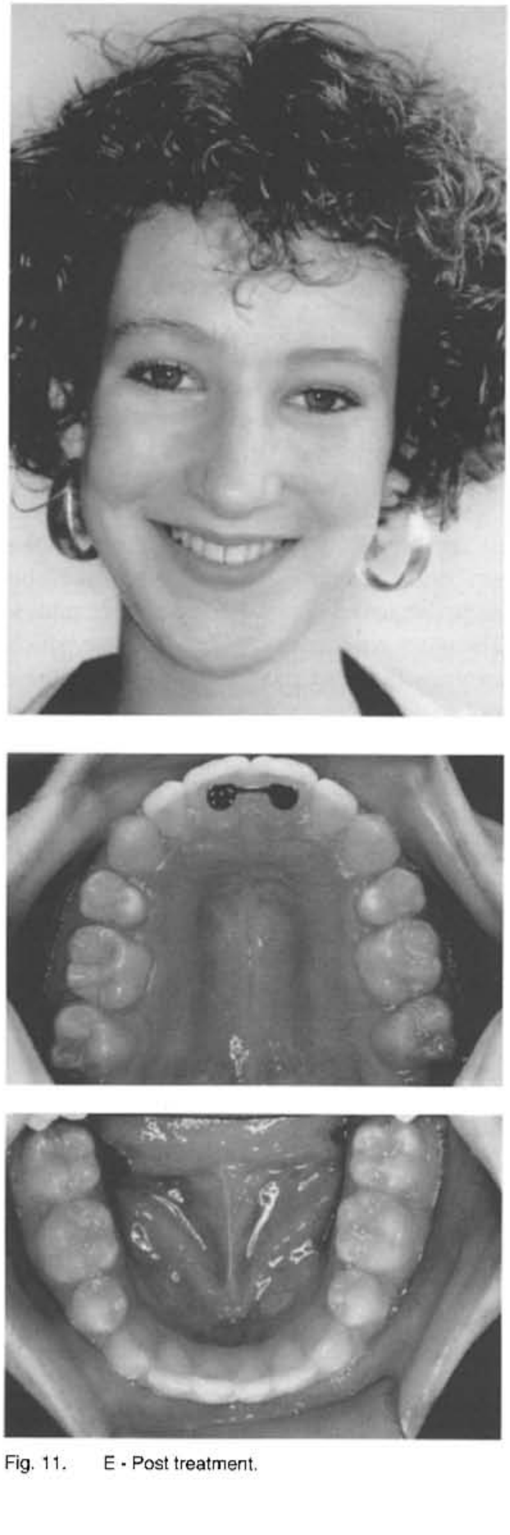


Fig. 11. E - Post treatment.

EXTRA ORAL TRACTION (EOT)

Introduction

The use of extra oral traction or headgear has been advocated for the treatment of both Class II and Class III malocclusions. Kingsley (1880) was one of the first who demonstrated the use of headgear to successfully treat Class II malocclusions. Angle (1900) also used headgear initially, but with the increased use of inter-maxillary elastics in the early 1900's, headgear became less popular. With the advent of cephalometrics in the late 1930's it became apparent that significant skeletal changes did not occur with the use of the intra oral elastics. Kloehn (1947) re-introduced the concept of successful treatment of Class II malocclusions with headgear. Cephalometrics confirmed by utilising a simple neck strap to a face bow and by using a 300 to 400 gram distalising force to the maxillary teeth, skeletal changes could be achieved. The treatment of Class III malocclusions with headgear has also been demonstrated over many years. Chin cup headgear has been used in Class III malocclusions with prognathic mandibles, while reverse headgear or protraction headgear has been used in cases with a retrognathic maxilla.

Uses of headgear

Active

This term describes headgear which is used to achieve primarily orthopaedic movement, primarily dental movement or a combination of the two. To have a primary orthopaedic effect the force of the headgear must be transmitted to the maxillary sutures and be of sufficient magnitude and duration to influence sutural growth. It is impossible however, to achieve orthopaedic movement without some movement of the teeth as the forces of the headgear are transmitted through the dentition. To achieve a primarily dental movement the force must be transmitted to

the periodontal ligament with sufficient magnitude and duration to activate tooth movement. The force required will be dependent upon whether the buccal and/or labial teeth are moved 'en masse', or if individual teeth, such as upper first molars or canines are moved separately.

Passive

This term describes headgear which is used to reinforce intra-oral anchorage. Anchorage is the source of resistance to the reaction from active components of the appliance. For example headgear may be used to prevent the buccal segments moving mesially during retraction of the anterior teeth. Houston (1986) suggests that the headgear used for anchorage reinforcement should be adjusted to at least double the force generated by the active components of the intra-oral appliance.

There are four main types of headgear that can be attached to the teeth and supporting structures.

Facebow

The most widely used headgear attachment is the facebow which consists of the inner bow which fits into tubes attached to molar bands and an outer bow which is attached to either a neck strap, head cap or a combination of the two. The inner bow usually has a bayonet bend or U loop placed mesial to the molar tubes so the distalising force is transmitted to the molars. Some molar bands have stops placed distal to the headgear tube which achieves the same effect without the need for such bends in the inner bow. This does not however, allow for any adjustment in the anterio-posterior length of the inner bow, which may become necessary to clear the bow from the incisors as the molars are moved distally (Fig. 12).

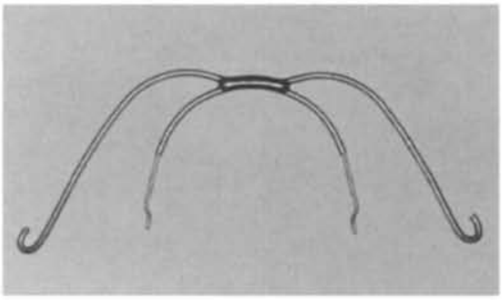


Fig. 12. Facebow - Bayonet bends have been placed in the inner bow mesial to the headgear tubes attached to the upper first molar bands.

J Hook

The 'J' Hook headgear attachment consists of two separate wires which have hooks anteriorly which can be clipped onto the archwire, usually mesial to the upper canines. The wires are constructed in a 'J' shape which enables them to pass forwards from their point of attachment to comfortably clear the corners of the mouth. They terminate adjacent to the cheeks where the posterior ends of the 'J' hooks are supported by the headcap with elastics applying a distal force between the hook and the headcap (Fig. 13).

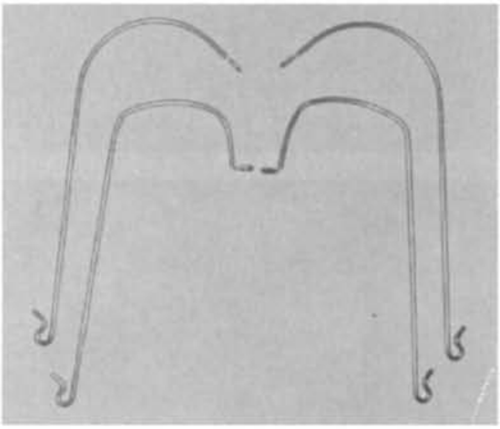


Fig. 13. Adjusted and unadjusted 'J' hooks - The inner set of 'J' hooks have been adjusted to fit onto the archwire mesial to the upper canines.

Protraction

Protraction headgear or Reverse headgear usually consists of pads which rest on the chin and forehead and are linked together by a wire framework. The framework has extensions which pass a short distance in front of the lips and have hooks in various positions for elastic bands. These bands pass from the frame work and are attached to the teeth via a fixed appliance or removable splint. (Fig. 14) Protraction headgear may be used in Class III cases where labially directed forces are applied to the upper incisors. It may also be used in cases of oligodontia where space closure is planned and the use of intermaxillary anchorage alone would result in excessive retroclination of the upper incisors. Delaire (1971) demonstrated the effectiveness of protraction headgear in moving the maxilla forward and can be useful in treating cases with a retrognathic maxilla such as cleft patients.

Chin cup

Chin cups have been used over many years in an attempt to restrict or alter further mandibular growth in Class III cases. Chin cups which direct a force through the condyle are used to inhibit growth in this area, while those that have their force directed below the condyle are used to redirect mandibular growth in a downward direction. Despite the reports of some favourable results most orthodontists have failed to observe significant clinical changes which have remained stable using chin cups. This may be due to the inherent nature of growth in Class III malocclusions or to the difficulty in directing an inhibitory force through the TMJ's. (Fig. 15)

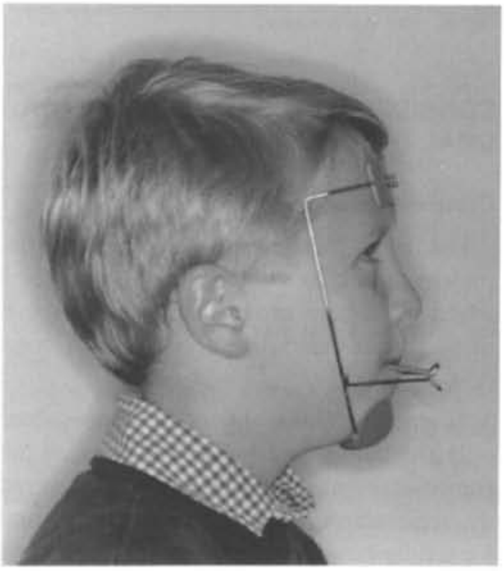


Fig. 14. Protraction or reverse headgear - A wire frame work supported by pads on the forehead and chin. Elastic bands pass from an upper fixed appliance or splint to the wire extension passing in front of the lips.

Fig. 15. Chin cup headgear.

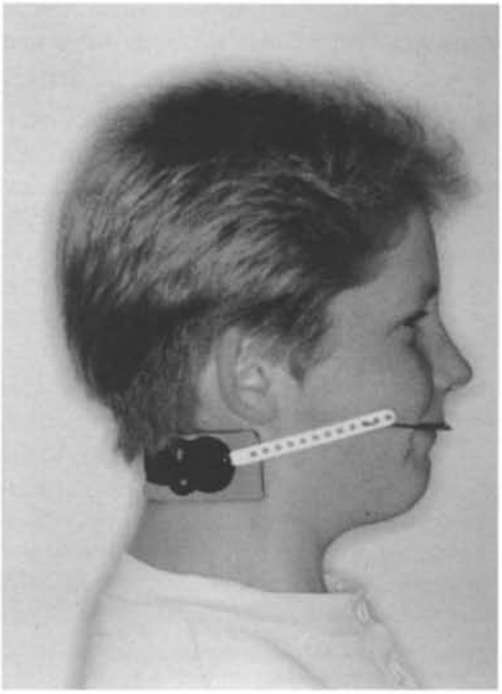
CONSIDERATIONS OF USING EXTRA ORAL TRACTION

Centre of rotation

The mechanical effects of headgear is dependent upon Newton's law of motion and when the centre of resistance to a force is distant from the point of application, rotation occurs.

When a facebow is used in a case were only the upper first molars are banded the centre of resistance for these teeth is around the trifurcation area. The geometric centre for a fully banded maxillary arch is thought to lie between the roots of the premolars, although this may vary depending upon the number of teeth banded, the size of the roots and the stiffness of the archwire.

If the force from the headgear does not pass through the centre of resistance, rotation will occur. The further the force from the centre of resistance, the greater the rotation that can be expected. This is an important consideration, not only in terms of positioning of the outer face bow and its length, but also the direction of force attached to this. There are three basic types of facebow headgear which determine the force directions. A low pull direction can be achieved with the use of a cervical or neck strap. A high pull force can be applied with the use of a occipital headcap. A straight pull or combination headgear involving both cervical and occipital pull may result in a force vector passing along or slightly above the occlusal plane (Fig. 16). If the length of the outer face bow is mesial or distal to the centre of resistance, tipping of the molars or occlusal plane can occur. Moreover it will determine whether the force vector will pass in front or behind of the centre resistance and hence the direction of rotation (Fig. 17).



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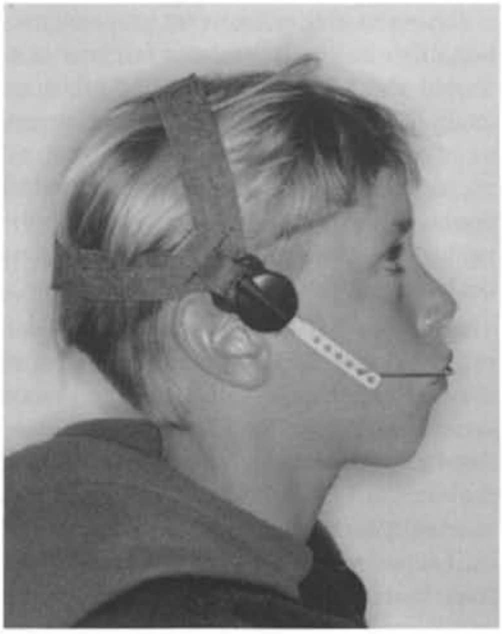

B

D

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Fig. 16. Headgear attached to facebow.

A - Low pull or cervical pull headgear.

B - High pull or occipital pull headgear.

C - Straight pull or combination pull headgear.

D - High pull 'J' hook headgear.

The vertical position of the outer bow will also influence any extrusion or intrusion force vectors to the teeth. Murray-Field and Cross (1970) suggest excessive tipping of the maxilla can occur with low pull headgear. This is due to the extrusion of posterior teeth and is more important in patients with a high maxillary-mandibular plane angle. In these cases, high pull headgear should be used to limit any posterior extrusion. However, this is less efficient for distal movement. For patients who have a low maxillary-mandibular plane. angle, low pull headgear may be indicated if molar extrusion is required. To achieve distal movement along the occlusal plane without molar extrusion or tipping a straight pull or combination headgear is often used.

The lateral position of the outer bow can also influence the force vectors and if one outer arm is more lateral than the other, then the molar on that side will be moved more distally and palatally compared with the opposite molar. This may be useful when unilateral distal movement is required although close attention should be made to avoid any unwanted lateral tooth movements and possible crossbite/scissor-bite development.

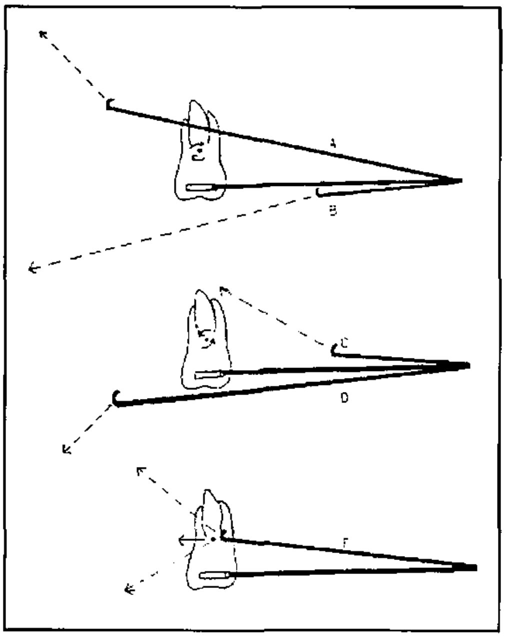

Fig. 17. Direction of force with a facebow attached to molar tubes

A - Long facebow arm, resultant line of force from high pull headgear passes distal and apical to the centre of reistance - distal crown tipping.

B - Short facebow arm, resultant line of force from low pull headgear passes mesial and occlusal to the centre of reistance - distal crown tipping.

C - Short facebow arm, resultant line of force from high pull headgear passes mesial and apical to the centre of reistance - mesial crown tipping.

D - Long facebow arm, resultant line of force from low pull headgear passes distal and occlusal to the centre of reistance - mesial crown tipping.

E - Medium facebow arm, resultant line of force from "combination" headgear passes through the centre of reistance - bodily tooth movement.

The positioning of the molar extra oral traction tubes in which the inner facebow rests should also be considered. If the tubes are gingivally placed they will be closer to the centre of resistance. Occlusally placed extra oral traction tubes increase the potential for molar tipping although in this position they allow the patient easier access to the tubes when fitting the inner bow as well as for easier cleaning.

The use of 'J' hooks anteriorly can also lead to undesirable tipping of the teeth and/or the occlusal plane if the centre of resistance is not considered. If the force vector passes distal and inferior to the centre of resistance the maxilla may tip downward anteriorly, making Class II correction more difficult. If the canine is retracted with 'J' hooks and the force vector passed inferior to the centre of resistance distal crown tipping can be expected. For this reason high pull 'J' hook headgear is often used to retract the maxillary teeth although some labial segment intrusion can also be expected.

Magnitude of forces

The force used with headgear will be dependent upon the treatment aims for each individual case. Treatment aimed at orthopaedic changes require heavier forces (500 to 1000 grams), while changes to tooth positions require lighter forces (150 to 450 grams). It is however, impossible to achieve an orthopaedic effect without causing some movement of the teeth to which the headgear is attached.

Duration of forces

Ricketts (1960) suggests that cervical traction worn for approximately 12 to 14 hours per day will move maxillary molars distally as well as altering the position of the maxillary complex in a growing child. Proffit (1990) suggests that greater orthopaedic effects are achieved if the headgear is worn 12 to 14 hours a day while continuous wear allows for greater tooth move-

ments to occur. To reinforce anchorage a minimum of 8 to 10 hours is required, with more hours to achieve distal movement of the maxillary molars.

Patient safety

Due to previous reports of facial injuries related to the use of headgear most systems available have some safety device incorporated in their design (Postlethwaite 1989). This allows the facebow or 'J' hook to become unattached if they are inadvertently pulled away from the face. When fitting headgear ensure both ends of the inner and outer arms are smooth and the external hooks are bent to reduce any potential trauma. Patients and parents should be warned of any possible hazards and the patient should not wear the headgear during sport or play.

Patient supervision

To be effective the headgear is dependent upon the patient's own cooperation. Patient resistance to these appliances are related mainly to appearance as well as initial discomfort to the teeth when first fitted. For this reason careful monitoring of tooth movement and encouragement to the patient is required to ensure good patient compliance.

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13
Functional Appliances

Colin C Twelftree

INTRODUCTION

This chapter attempts to cover a huge subject area in a few pages. In order to do this, it is a compilation of the author's approach to this subject from a clinical point of view. As personal clinical practises necessarily vary with time and experience, it is a distillation of the author's point of view at this moment in time. It is intended to allow the neophyte orthodontist to begin to utilise functional appliances in daily practice. The reader is encouraged to consult the reference list for a broader appreciation of this fascinating subject.

HISTORY

Functional appliances are a group of removable appliances which treat malocclusions either by moving teeth using forces derived from the functional matrix or by directly affecting the functional matrix and consequently producing a change in the skeletal and dental components. These appliances were initially developed in Europe, partially in response to the social and economic attitudes that prevailed in that part of the world. Simultaneously, a more mechanistic attitude in the United States of America was responsible for the development of fixed appliances which primarily aim to move teeth directly. Fortunately for our patients, each approach has learnt from the other and the specialist orthodontist should be familiar with, and be able to utilise, the advantages of each approach. At this point in time, it is possibly unfortunate that the benefits of functional appliances are not well recognised within the formal orthodontic specialty of the United States and that may be a reason why an increasing proportion of orthodontic treatment in that country is being provided by non-specialists.

The modern orthodontist is required to understand and utilise both aspects of treatment for the benefit of his patients as each has its own inherent advantages and disadvantages which may be individually prescribed for particular orthodontic problems.

MODES OF ACTION

In treating a malocclusion, functional appliances can affect the dento - alveolar elements, the skeletal elements or the functional matrix of the total problem in varying degrees (Bishara 1989). Different appliances may concentrate on particular aspects in producing effects, but most appliances have some effect on each of the above elements.

For example, the function regulator developed by Dr Frankel predominantly influences the functional matrix which then produces the desired effects on the skeletal and dentoalveolar elements (Frankel 1989). Activators as a group primarily affect the dentoalveolar structures in treating a malocclusion (Harvold 1974). To directly affect skeletal elements is more difficult and clinical results have yet to duplicate the changes produced in animal studies. However, the Clark Twin Block appears to produce promising mandibular changes (Clark W 1995). The high level of forces produced by a head gear acting on the maxilla may also result in orthopaedic changes to this portion of the skeleton (Teuscher 1986,1985).

Thus, there a three possible modes of action of a functional appliance;

a) dento - alveolar

b) skeletal

c) functional matrix effects

Dentoalveolar

In the treatment of malocclusion with fixed appliances, forces are directed to the tooth through brackets directly attached. The forces are primarily derived from active archwire and elastic elements although extraoral forces may be added to favourably affect the balance. The forces that functional appliances exert on teeth are primarily derived from the muscles. They are produced by encouraging muscles to contract or by stretching muscles in the manner of stretching an elastic, utilising the visco elastic properties of muscles (Woodside 1984). The forces are usually applied to groups of teeth as individual control is difficult.

The forces applied to the teeth may be considered in three dimensions; anteroposterior, lateral and vertical.

Anteroposterior

These forces are similar to using muscles as Class II elastics but tend to tip anterior teeth labiolingually unless the design of the appliance prevents these movements.

In treating malocclusions with functional appliances, tipping movements are usually undesirable as torque values can be lost.

Lateral

Unless the functional matrix can be altered, buccal expansion of arches is not stable and is to be avoided. However, passive expansion is necessary to maintain lateral co-ordination of arches in the buccal segments when class II relationships are being corrected. The passive expansion produced by the function regulator appears to be stable but may not be predictably achieved (Frankel 1989).

The functional matrix can be affected by an alteration of muscle action. The obvious example is the correction of a lower lip trap. As the relationship of the upper and lower anterior teeth to the muscles is substantially and permanently altered, stable forward positioning of the lower incisors can be expected. If the pattern of respiration can be altered from oral to nasal respiration then the functional matrix has been permanently altered with stable effects on the dentition.

Vertical

The effect on the vertical dimension by functional appliances is probably the least appreciated and most important mode of action. The primary work on the subject was described by Harvold in his classic volume (Harvold 1974). An understanding of the importance of the vertical position of the dentition within the skeletal framework is crucial to an understanding of treatment with all functional appliances.

The functional occlusal plane is the occlusal plane established by the posterior teeth that have occlusal antagonists. The vertical position and angulation of the occlusal plane must be compatible with the skeletal framework to achieve satisfactory anteroposterior relationships of the dental arches.

The anteroposterior position of the upper and lower anterior teeth within each alveolar process is relatively restricted and not amenable to change by fixed or functional appliances. In particular, the position of the lower incisor is relatively immutable. The position of the apices of the upper and lower incisors is used as a measure of the anteroposterior position of the anterior denture supporting portion of the maxilla and mandible. In assessing this position, the anterior teeth are required to be tipped to an acceptable angulation. The relationship of these points to the functional occlusal plane is a measure of the extent of the malocclusion as described by Harvold.

In the Harvold analysis, to attain a Class I occlusion, the line joining the apices of the upper and lower anterior teeth is required to be at an angulation of 89 degrees to the functional occlusal plane, (Fig 1.) plus or minus 5 degrees (Fig 2 & 3). This angle may be varied by altering the angulation of the occlusal plane and this is achieved by vertical manipulation of the posterior teeth.

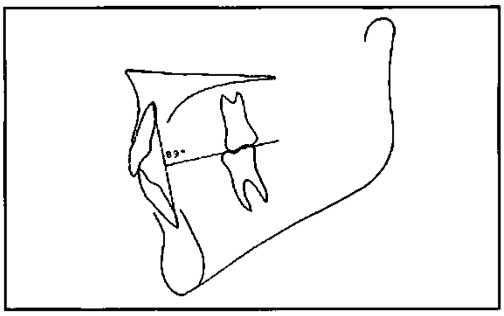


Fig. 1. An 'ideal' occlusion has an angle of approximately 89 degrees between the occlusal plane and the incisor line.

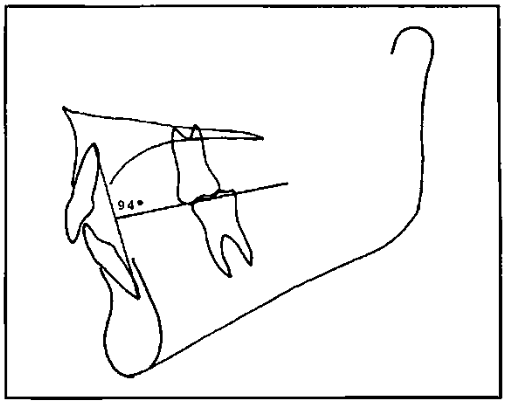


Fig. 2. If the angle is greater than 94 degrees due to the skeletal relationship, normal occlusion may not be obtainable by differential eruption alone.
It may be necessary to alter the angle by skeletal modification or bodily movement of teeth.

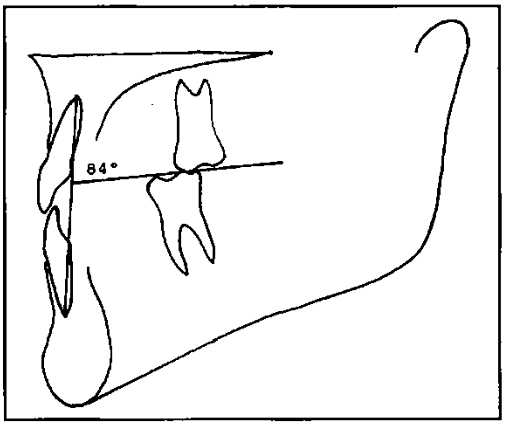


Fig. 3. If the angle is less than 84 degrees skeletal modification may be required to enable normal occlusion to be achieved by modification of the eruption patterns of the dentition.

The upper molar teeth erupt in a downward and forward direction (Fig 4) and the lower molar teeth erupt at an angulation of approximately 90 degrees to the lower border of the mandible (Fig 5). Therefore, the vertical position at which these teeth contact determines their anteroposterior relationship (Fig 6). The higher this position the more anterior is the position of the lower molar relative to the upper molar. This feature is used in functional treatment to alter the

anteroposterior relationship of the arches by manipulation of their vertical position. The absolute anteroposterior position of the arches is not altered. This alteration of the vertical position of the molars alters the angulation of the functional occlusal plane.

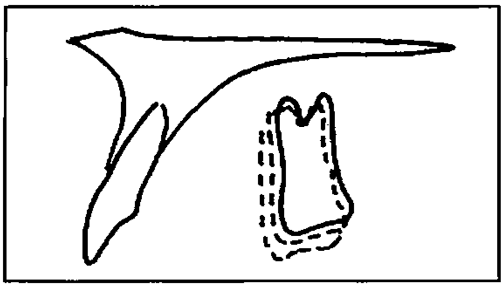


Fig. 4. Normal eruption of the upper molar is in a downward and forward direction relative to the palatal plane.

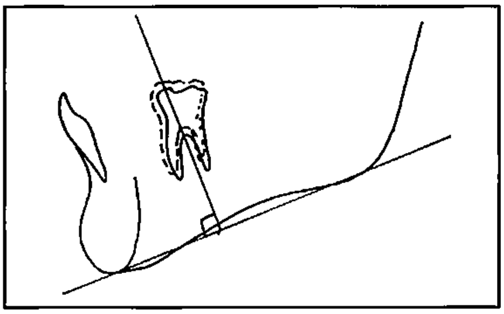


Fig. 5. Normal eruption of the lower molar is at an angle of approximately 90 degrees to the mandibular plane and upward and forward to the palatal plane and upper molar.

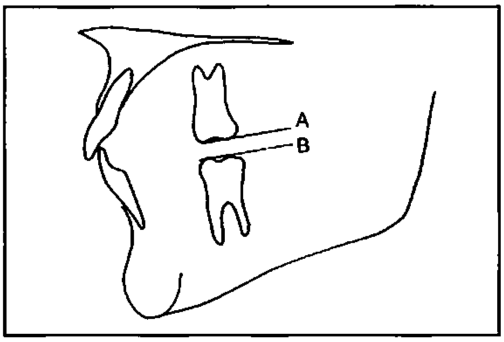


Fig. 6. The relative eruption of the molars is crucial for the establishment of normal interdigitation. If the occlusal plane is established at level A there would be a Class I molar relationship but an occlusal plane at level B would have a Class II molar relationship.

Similarly, the anteroposterior relationship of the upper and lower anterior teeth is altered by manipulation of their vertical positions. The more relative eruption of the upper incisor the greater the overjet and the more vertical eruption of the lower incisor the less the positive overjet. This feature is used by functional appliances in the correction of overjet without tipping anterior teeth or moving them bodily anteriorly or posteriorly (Fig 7,8 & 9).

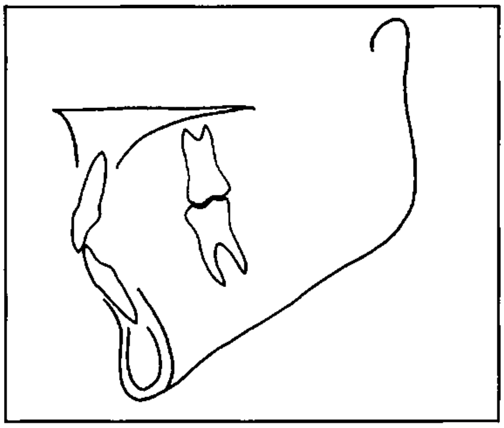


Fig. 7. For a satisfactory (or Class I incisor relationship), there is harmony between the amount of relative eruption of the incisors.

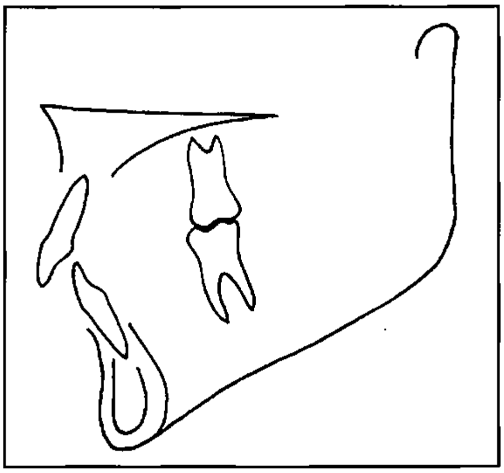


Fig. 8. Excessive eruption of maxillary incisors or relative intrusion of mandibular incisors increases overjet and overbite.

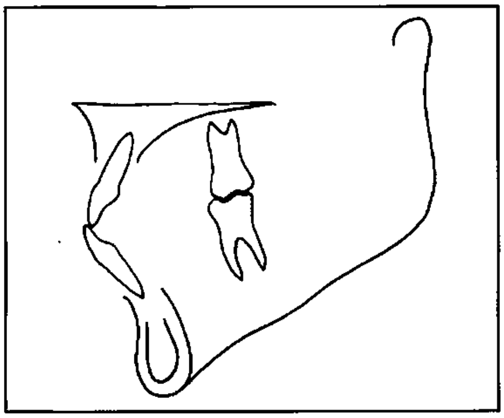


Fig. 9. Inhibition of maxillary incisor eruption or increased mandibular incisor eruption reduces positive overjet and may result in anterior crossbite.

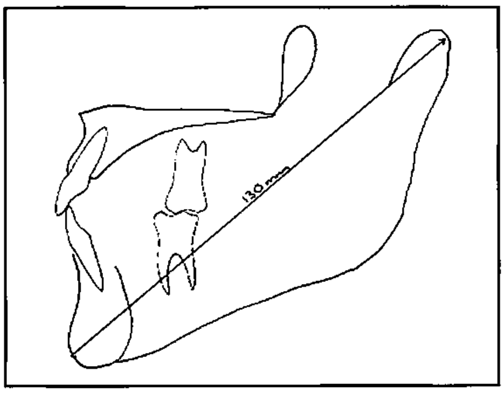


Fig. 10. With a 'normal' skeletal relationship, harmonious relative eruption of the maxillary and mandibular teeth results in a Class I dental pattern.

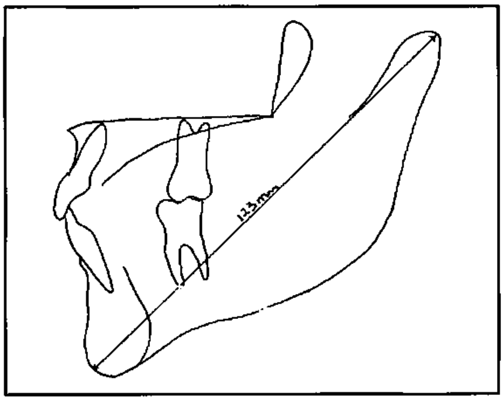


Fig. 11. With a relatively shorter mandible (Class II pattern) less maxillary dental eruption and/or increased mandibular dental eruption is required to maintain a Class I dental pattern.

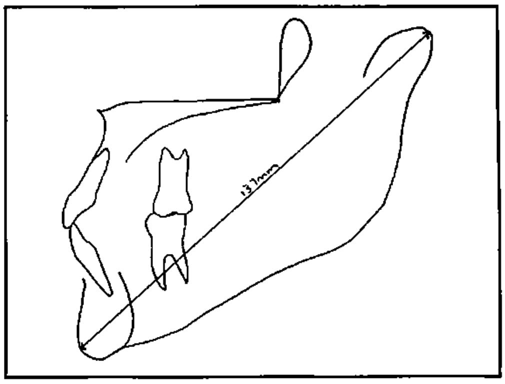


Fig. 12. With a relatively longer mandible (Class III pattern) increased maxillary dental eruption and/or decreased mandibular dental eruption is required to maintain a Class I dental pattern.

Vertical manipulation of the arches explains how variation in jaw lengths may be compensated for to produce Angle Class I dental relationships on a range of skeletal patterns (Fig 10,11 &12). All functional appliances designed to treat Angle Class II malocclusions prevent eruption of the upper posterior teeth and generally the upper anterior teeth. Selective eruption of teeth in the lower arch is usually permitted. In this way, a Class II buccal occlusion can be changed into a Class I buccal occlusion merely by affecting the vertical position of the teeth without requiring any antero-posterior changes in the position of each arch relative to its respective skeletal element. Fixed appliance systems also utilise these principles although this is less well recognised.

Skeletal

Manipulation of the skeletal elements of the orofacial region has long been the "holy grail" of functional orthodontists. However, the vast number of claims that have been made have never been substantiated by scientific research (Nelson 1993). Manipulation of skeletal elements is a highly desirable objective and the small changes that may be achieved are both beneficial and cumulative.

Petrovic (1981) has demonstrated experimentally that it is possible to encourage a mandible to increase its length, but this has not been replicated clinically. This may be because it is difficult to duplicate animal experimental conditions in terms of patient compliance. However, the results obtained from true full time functional appliances like the Clark Twin Block are promising. The full time Herbst appliance does not increase mandibular length but this appliance may not be considered truly functional (Wieslander 1993).

All skeletal manipulation results may be pedantically divided into orthopaedic and functional components, depending on the source of action and the level of force. For example, the use of a head gear to restrain a maxilla is considered an orthopaedic movement while the repositioning of a mandible forward with a function regulator is considered to be a functional effect. Each produces a change in skeletal relationships.

The possible skeletal changes that can be achieved can be subdivided into maxillary and mandibular changes and further subdivided in terms of vertical or anteroposterior changes.

Maxilla

a) Vertical

The vertical position of the maxilla may be influenced by a vertical or high pull headgear applied to a functional appliance. It is possible to maintain the vertical position of the maxilla but not actually move it upwards (Teuscher 1985). This is an orthopaedic movement.

b) Anteroposterior

A head gear to a functional appliance can move a maxilla distally or prevent further forward growth of the maxilla to effect a relative distal repositioning (Pfeiffer 1972). These changes are orthopaedic.

A maxilla may be moved forward by using a reverse head gear to either a fixed appliance or, desirably, a maxilla disarticulated by a rapid maxillary expansion appliance, and this is also an orthopaedic movement (McNamara 1987). A function regulator III or a Class III Activator can encourage forward positioning of 'A' point (Frankel 1989).

Mandible

a) Vertical

Vertical movement of the mandible results in an increase in face height. In treatment of Class II malocclusions, it is often necessary to increase the face height to provide space for the vertical manipulation of the dentition. This increase of face height may be desirable or undesirable and must be anticipated and planned for. An increase in face height is often desirable in the treatment of Class III malocclusions as the anterior position of the mandible is reduced through rotation. This effect may be produced by a chin cup or an appropriately designed activator (Woodside 1984).

It is not considered possible to decrease face height although it may be maintained by relying on autorotation of the mandible to a restrained maxilla.

b) Anteroposterior

The anatomy of the mandible and its attachment to the base of the skull prevents distal repositioning of this structure.

Forward repositioning of the mandible has always been the prime objective of most functional appliance treatment. The forward positioning of pogonion may be achieved by increasing the length of the mandible or by repositioning the bone which implies alteration of the anatomy or position of the articulation.

The length of the mandible can be increased experimentally but this has not been demonstrated clinically. Claims are constantly being made that mandibles can be grown in length but there is no hard evidence to support this.

It is possible to reposition the mandible forward; the only discussion at present is on the degree to which this is possible. This implies moving the point of the attachment of the mandible to the base of the skull and includes remodelling of the glenoid fossa (Woodside 1987). That this occurs has been shown experimentally and clinically; this effect may be responsible for some of the claimed increases in mandibular length. However, as long as pogonion is moved forward with no iatrogenic effects on the temporomandibular joint, then the desirable objectives of treatment have been achieved. As all small effects on the mandible can be cumulative the impressive results achieved by some appliances are often hard to quantify in terms of the location of the precise changes that occur.

Functional matrix

The functional matrix is the complex that surrounds and influences the skeletal and dental elements of the orofacial structures. It is comprised of muscles and connective tissues but the requirements of the functioning spaces are also crucial. The most important functioning space is the airway. It is important to realise that the requirements of a functional matrix are not only related to overt functioning, for example, swallowing, speech and eating, but also the more passive functions of breathing and posture. It is the resting or postural functional matrix which has the most influence upon the dentition.

Alteration of the functional matrix produces effects on the bones and dentition. This was elegantly demonstrated in Harvold's classic experiments (Harvold 1974). The important point from these results is not necessarily the specific changes that were achieved but the fact that an effect was produced.

A common thread running through all functional appliance treatments is the desirability of achieving nasal respiration with a relaxed postural lip contact. The effect of oral respiration on the dentition is still a controversial subject but there is universal agreement that it has a deleterious effect and should be changed where possible (Frankel 1989).

The ability to alter the size, shape and position of muscles is utilised to varying degrees by some functional appliances but the relevance and importance of these changes has not been scientifically demonstrated.

The relationships and position of the dentition are profoundly affected by tongue posture and function. Whether this can be affected by treatment is unpredictable but functional appliances attempt to change an undesirable tongue pattern.

DIAGNOSIS AND TREATMENT PLANNING

The diagnosis of a malocclusion is determining the problem, the cause of the problem and, by implication, what is required for correction, on the assumption that one wishes to treat as much as possible the cause and not the effect.

It is not always possible to determine the actual cause of a problem as cause and effect are inextricably related. For example, if it is determined that mouth breathing is the cause of the malocclusion and associated with the mouth breathing is an occluded nasal airway, then the question is whether the mouth breathing caused the blockage of the airway or an inability to breath through the nose resulted in the mouth breathing pattern. If the oral respiratory pattern is

primary then using an appliance that occludes the oral airway will be effective in converting the patient to a pattern of nasal respiration. However, if nasal respiration is not possible then such an appliance would not be tolerated. Similarly, if tonsilar and adenoidal tissues are blocking an airway, their removal may or may not be justified.

Treatment planning involves determining the treatment to be performed and the timing of the various steps.

The causes of malocclusion are traditionally divided into genetic and environmental causes but it is difficult to accurately define the proportions of each in any specific case. This also depends on the definition of an environmental or genetic cause. For example, mouth breathing is usually called an environmental cause but it could quite possibly be inherited. If the cause of the problem is truly genetic then it is usually not possible to remove; treatments attempting this have a poor prognosis. If the cause of the malocclusion is environmental then it is usually possible to directly treat the cause and expect a stable result.

Defining the problem is often the best method of reaching a diagnosis and treatment plan.

The chief concerns of the patient are the initial problems which require consideration and these range from irregular teeth to malpositioned arches and disturbances of facial balance. The patient does not normally define causes to the presenting problem.

The clinician, in defining problems, adds the element of cause. For example, irregular teeth may be due to a tooth size - jaw size discrepancy or to actual malpositioning of the individual teeth. An apparently prominent upper arch could be caused by a forward position of the maxilla, forward position of the maxillary denture or a recessive mandible. An aberrant facial balance could be due to a skeletal disharmony or abnormalities of the soft tissue position or function.

However, the purpose of this chapter is not to discuss causes of malocclusion but to suggest a method of approaching them. Once the problem is defined and causes described it is possible to decide on a treatment approach. There is usually one major cause which determines the approach to the treatment. This major cause can be described as a limiting factor of the treatment. For example, if a recessive mandible is the major cause of a Class II malocclusion then treatment should be directed towards moving the mandible forward as much as possible.

Treatment

Treatment can affect either the skeletal elements, the soft tissues or the dentoalveolar structures.

Skeletal

The skeletal analysis should determine whether there is a satisfactory skeletal framework within which the denture can be repositioned or whether the prognosis demands an alteration of this framework. In functional orthodontic treatment, the primary objective is to normalise the relationships of the skeletal elements as much as possible to minimise camouflage type dentoalveolar movements. It is obviously not possible to produce a Class I skeletal pattern for all patients but that is the primary objective. If it is not possible to functionally produce a satisfactory skeletal relationship then orthognathic surgery may need to be considered. It is desirable to decide very early in the planning of a case whether it is surgical or functional. It is poor treatment planning to use a functional appliance and then rely on surgery to complete the correction.

Soft tissue

Effects on the soft tissue are usually concurrent with skeletal modification and different appliances have varying capabilities of soft tissue modification. These may involve muscle exercises, adaption of muscle function or airway modification. The most common example of this is using a closed activator to discourage mouth breathing and encourage nasal respiration.

Dento alveolar

Treatment to the dentoalveolar complex, especially in the vertical dimension, is the most common effect of functional appliances. Anteroposterior movements may be required but are essentially a camouflage type of movement and should be minimised in functional treatment.

Timing of Treatment

The timing of functional treatment is more important than the timing of fixed appliance treatment. The potential iatrogenic effects of fixed appliances limit their long term use and provide a positive disincentive to inefficient or extended treatment. The reverse is true for functional appliances and as they are often not demanding on patients, it is all too easy to extend treatment unnecessarily without proper planning.

As most functional appliances rely on the patient to be actively growing during treatment, it follows that the faster growth is occurring the faster the response and the shorter the treatment time. Whether the appliance is repositioning the mandible or manipulating the eruption of teeth, a period of active growth is desirable. Therefore, the most common time for treatment is during the pubertal growth spurt. This time can be predicted by

- Hand-wrist x-rays
- Observation of secondary sex characteristics
- History taking

It is the author's view that observation and history taking are sufficient to determine whether a patient is approaching or in their pubertal growth spurt.

The stage of maturation of the dentition is also relevant to treatment timing. Functional appliances basically move jaws and groups of teeth and do not significantly affect the individual position of teeth. Therefore, for high quality results, fixed appliances are necessary in a percentage of cases. The need for this is not entirely predictable and must be considered in a treatment plan. Fixed appliance treatment is usually performed after functional treatment although exceptions occur.

Considering the above, the timing of treatment can be divided into three categories

- Early treatment
- Definitive treatment
- Retentive treatment

Early functional appliance treatment

Early functional treatment is to intercept a developing problem to

a) improve aesthetics
b) decrease the risk of trauma to permanent anterior teeth
c) improve the eventual prognosis
d) decrease the length of definitive treatment
e) provide early correction of a deleterious habit

Ideal timing of early treatment is usually at a dental age of nine years when the four incisors have erupted. The deciduous canines are still firm and the dentition will be relatively stable for at least twelve months during the treatment period. At this age, children are usually socially aware of a developing malocclusion and this enhances their co-operation. The most common situation encountered is the correction of a Class II

malocclusion with a large overjet caused by a recessive mandible. The early treatment is to reposition the mandible forward without retraction of the upper anterior teeth. The author routinely uses a Clark Twin Block for this treatment which is completed within twelve months. Following correction, all appliances are discontinued and the patient, parents and operator have a rest for two or three years until the final definitive treatment (or second phase) is necessary. During this resting period, there is naturally some rebound but the author prefers to observe this rather than retain for a long period of time. The extent of the rebound provides additional information for planning the later treatment. Patient co-operation is limited and a significant break from treatment of two or three years maximises co-operation at the more important final or permanent treatment period. During this resting time the dentition is changing and it is more difficult to wear orthodontic appliances.

Definitive Treatment

Definitive functional treatment is carried out as a total treatment in itself or associated with fixed appliance treatment. Timing of these cases is ideally during the pubertal growth spurt but treatment is not initiated until there is less than twelve months before the permanent dentition is complete. The most common situation is to use a functional appliance to correct a developing malocclusion in the mixed or early permanent dentition stage of development. If the timing is correct, the gross malocclusion is largely corrected after twelve months functional treatment, by which time the permanent dentition has completely erupted. The necessity or otherwise for fixed appliance treatment can then be determined. If final detailing is necessary, then usually twelve months only of full banding is required, which concludes the active treatment period within two years. If full banding is not required, then a second year of functional treatment is indicated. Normal retention follows the two years of active treatment although the functional appliance may be used as the retainer. The author feels that it is highly desirable, and usually achievable, to complete definitive treatment within two years.

Functional appliances can occasionally be used during fixed appliance treatment. If a skeletal malocclusion has significant dental compensations, to treat the malocclusion functionally it is necessary to decompensate the arches as would be done before surgical treatment. A short period of fixed appliance treatment may be an efficient decompensation mechanism. A Class II division 2 incisor relationship on a Class II skeletal discrepancy is the most common situation. The retroclined upper anterior teeth are proclined with either a fixed or removable appliance to create the necessary overjet for construction of a Class II functional appliance. Following the functional treatment, a period of full banding may be necessary for final detailing. Obviously, very careful planning is necessary to minimise the total treatment time and the author feels an acceptable approach is six months of decompensation, twelve months of functional treatment and twelve months of full banding.

Retentive Treatment

Functional appliances are useful retainers following orthodontic correction of skeletal problems. A Class III functional appliance can be used to retain a corrected malocclusion in a patient who is still growing. Following the correction of a Class II malocclusion, where skeletal or soft tissue factors indicate a doubtful prognosis, a functional appliance can be a useful retainer. For the experienced operator, it is possible to use fixed appliances to decompensate a case as one would with a surgical treatment and

subsequently use a functional appliance to produce the required skeletal change without the need to use fixed appliances again.

APPLIANCES

There are available myriad functional appliances, all with their advantages and disadvantages. The proponents of each appliance are naturally enthusiastic about the appliance's advantages and vocal regarding the disadvantages of competing appliances. The following appliances have been used by the author for many years and have been found to satisfactorily treat the vast majority of cases encountered in orthodontic practice. It is recommended that they provide an excellent starting point for the inexperienced operator and provide a basis for critical evaluation of other appliances which may be described in the literature.

Activator

Activators are a large group of acrylic removable functional appliances. The type described here is a combination of the activator developed by Professor Harvold and Dr Woodside with elements of the activator used by Dr Teuscher. It is a robust, well tolerated appliance which is worn at night time only and produces excellent dento-alveolar changes with good vertical control. Soft tissue function is routinely improved.

Description

The appliance is basically a block of acrylic between the upper and lower arches acting to maintain a vertical separation determined by the construction bite (Fig 13). The acrylic prevents eruption of teeth and can be trimmed to allow selective eruption to occur. This will alter the level and inclination of the functional occlusal plane to achieve relative antero-posterior changes of the buccal occlusion. Lateral movements of the arches are permitted.

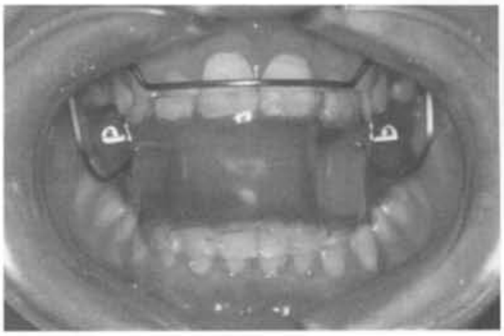


Fig. 13. A standard appliance showing incisal capping, the wire work and headgear tube position. Upper molar eruption is prevented and lower molar eruption permitted.

The upper and lower anterior teeth are capped labially with acrylic to the level of the gingival papillae of the upper and lower central incisors. This acrylic capping minimises labial tipping of the lower anterior teeth and lingual tipping of the upper anterior teeth. The eruption of the incisors is naturally prevented. Selective removal of the capping to allow tipping and eruption is occasionally required.

The acrylic between the arches is complete to prevent oral respiration and promote nasal respiration. In the author's experience, this blockage of the mouth causes far fewer problems for the patient than may be expected. The importance of this is emphasised by the parents of patients noticing and voluntarily commenting quite early in treatment, that the children tend to keep their lips together during the day. As the patient is forced into a nasal respiratory pattern during sleeping, which is encouraged during the day, the patient suffers fewer respiratory problems and cooperation is automatically enhanced. In rare cases, approximately 5% of patients, a temporary anterior air hole can be provided between the incisor teeth to encourage compliance. This air hole can then be closed with cold cure acrylic after a few weeks of continuous night wear.

The buccal wire work of the appliance holds the soft tissues away from the arches to permit spontaneous lateral expansion of the upper buccal teeth as the anteroposterior relationships are corrected. In twenty years of practice the author has never created a posterior crossbite in the correction of a Class II malocclusion and can only assume that the presence of the buccal wires is essential.

A head gear tube is positioned in the area immediately below the upper first premolar. A high pull head gear may be used as a training aid in the early stages of treatment to help patients from subconsciously removing the appliance during sleep. As the force applied by the head gear is directed to the whole upper arch, high levels of force may be desirable to maintain vertical control. A force of thirty two ounces on each side can be used. The author uses the Unitek high pull head gear which can be adjusted up to a force level of thirty two ounces (Fig 14). The outerbow of the head gear must be kept very short to maximise the vertical component of force and minimise the distal component of force provided by the head gear. A true vertical head gear is desirable but is often not practical. The direction of force can be adjusted by alteration of the angle of the outerbow. Some cases require the force to be directed anteriorly to reduce a gummy smile but more commonly the forces are directed through the centroid of the maxilla to minimise vertical development of the whole arch.

Deep sublingual extensions of the activator are necessary to hold the mandible in the appliance and to bolster anchorage.

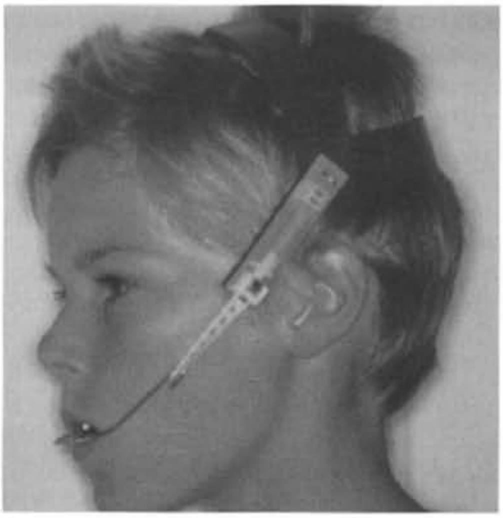


Fig. 14. A standard appliance with high pull headgear attached to a super short facebow.

Bite Registration

The construction bite activates the appliance. For this appliance, the author recommends an edge to edge incisor relationship and sufficient vertical separation to stretch jaw muscles well beyond the rest position of the mandible. This ensures that they remain stretched during sleep to maintain the force level on the dentition. The visco-elastic properties of the muscles are utilised. Sufficient vertical separation is necessary to discourage subconscious removal of the appliance during sleep.

Practically, this translates into a separation of eight wooden tongue spatulas between the incisor teeth in most cases (Fig. 15). This separation can be decreased in cases showing an excess in vertical dimension where there is a decreased freeway space. If the patient is unable to open his mouth sufficiently past a separation of 8 tongue depressors then it is not possible to insert the appliance. It is rarely that the author uses less than six tongue depressors.

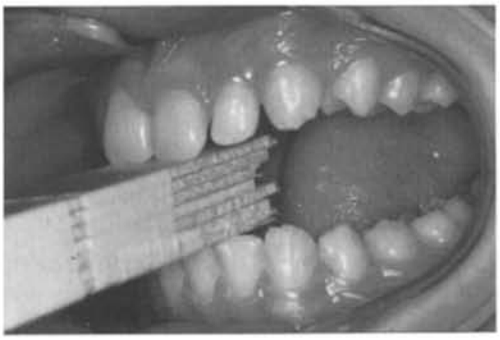


Fig. 15. Standard separation of arches for bite registration of a patient with average freeway space.

The bite registration technique is to tape the selected number of tongue depressors together and have the patient practise biting into an edge to edge relationship. Grooves can be placed in the tongue depressors to ensure correct incisor position. Two sheets of red boxing wax are softened under hot water and each is folded into thirds and then into halves and the tongue depressors are pushed between the two wax blocks to form a solid lump of wax that will not distort following removal from the mouth (Fig. 16). A horseshoe section of wax used to record the bite, may permit distortion. The wax block is placed on the upper arch. Slowly and gently, with a relaxed patient, it is a simple matter to guide the mandible up and forward into the desired relationship until the lower incisors touch the tongue depressors. The wax block is removed, chilled and returned to the mouth for checking. The upper and lower dental midlines should be coincident unless there has been significant dental drift. Generally, the mandibular body is kept in a central position.

The jaw registration is sent to a laboratory with alginate impressions of each arch showing good extension, especially in the sublingual area. It is important that the impressions show no sign of wax or impression tray impingement on the soft tissues to avoid production of sore spots.

Laboratory construction details may be found in text books.

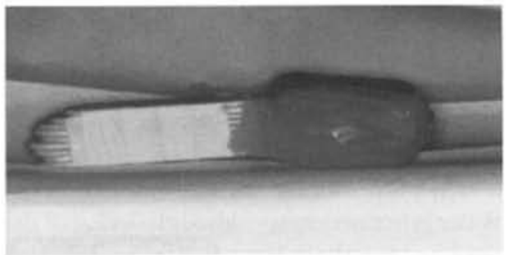


Fig. 16. A red wax construction bite.

Insertion and Management

The appliance is inserted with the patient alone and relaxed. The presence of a parent during the insertion is usually counter-productive. The presence of the clinician may also be counterproductive as many patients are more relaxed alone or in the presence of an assistant. After instruction for insertion and removal of the appliance the patient is left to quietly read for twenty minutes to ensure complete comfort. During this time, the patient is continually checked and praised. Naturally, any sore spots are relieved at this time. The parent is then introduced and instructions are given by the clinician. It is important to exude an air of confidence. The author feels that any failures of functional treatment due to patient cooperation are the fault of the clinician and not the patient. The attitude of the clinician is of paramount importance to give confidence to the patient and parent in the initial stages.

The appliances are worn during sleep and for two hours before sleep. Most patients are not able to wear the appliance all night initially and take approximately three nights before they are able to do so. If after that time the appliance is still being discarded

during sleep, then extra before bed wear is encouraged. The patient is instructed that there should be no pain at all except for the upper anterior teeth which may be sore for about ten minutes in the morning. No temporomandibular joint pain should be experienced. The patient is instructed to clean the appliance with cold water and an appropriate detergent each morning following removal, and to store their appliance in a safe place during the day. Immersion in water is not necessary although drying of the appliance is discouraged. It is emphasised that the use of the appliance is the responsibility of the patient and not the parent and they are reappointed to return in one week.

At the second appointment, the patient is initially seen alone. If they are able to wear the appliance all night and are not experiencing any pain they are then praised and the parent is summoned. A following appointment in six weeks is then made but the patient is warned to contact the surgery immediately if any problems develop.

If the patient is not able to wear the appliance all night and is experiencing any pain then the cause of the pain is removed, the parent informed and the patient reappointed in one week.

If the appliance is still not able to be worn all night and there is no pain the patient is reassured, the parent informed and reappointed in one week.

If the appliance is still not worn all night and there are no obvious problems, then a temporary breathing hole is added through the acrylic between the incisors. This hole should have a minimum diameter of 5mm. The parent is informed and the patient reappointed in one week.

If the appliance is still not being worn all night then a head gear is added as a training aid, if not already worn. The patient is advised to wear the appliance with the head gear for four nights and then try and wear the appliance without the head gear. Some patients require a head gear to hold the appliance in position during the whole treatment.

If after two weeks wearing the head gear the patient still removes the appliance during sleep, then abortion of the treament is highly recommended. Functional appliances of this type must be worn perfectly or not at all. Less than 1% of patients are not able to tolerate the appliance.

At the normal six weekly appointments, the appliance should be checked for a comfortable fit. If it is not worn correctly and the patient is growing it will quickly cease to fit. The patient's height is recorded at each appointment as speed of progress can be related to change in body height. Acrylic is removed to allow eruption of the selected teeth. The direction and level of head gear force is checked each visit and the force should be increased to thirty two ounces on each side in the initial stages of treatment.

After three months treatment, significant buccal occlusal changes should be noticed. Changes in overjet are not as predictable. At each appointment, the patient and the parents should be praised for their progress.

After twelve months treatment, the gross malocclusion should be virtually completely corrected in most cases. The final treatment plan is then determined. This may involve a rest for a few years, a move into full banding treatment or a decision to complete the treatment with a functional appliance only.

Utilisation

This appliance primarily affects the dentoalveolar structures and is used for correcting a non-crowded Class II division 1 malocclusion where skeletal relationship correction is not required. It is excellent at controlling the vertical position of the teeth to effect complete correction of a Class II

malocclusion. A high pull head gear may be added to improve vertical control and prevent an increase in anterior face height. The appliance holds the maxilla and the maxillary teeth vertically to allow the mandible to develop down and forward or, more accurately, to develop up into the space created by the relative intrusion of the maxillary complex and the normal increase in lower face height.

As the activator is dependent on alveolar and skeletal changes, it is most efficient in times of active growth. Therefore, it is best used as a part of later, or final treatment around the pubertal growth spurt. It is generally not used for early treatment unless vertical control is important. As it is worn at night time only, it has advantages for the patient of not interfering with their social life. There are no restrictions on eating. The intermittent wear of the appliance is probably why true skeletal changes are not observed.

It is not a demanding appliance for patients to wear and is suitable for long term treatments. This is classically two years of active treatment and twelve months of retention.

Clark Twin Block

This appliance is discussed completely in another chapter. However, to place its use in the context of this chapter a brief discussion is required. This author's other most used often functional appliance is the twin block. Being a full time appliance it is excellent at effecting mandibular repositioning and is less dependent on growth. The changes are produced very rapidly.

The author uses it as the main functional appliance for early treatment where quick mandibular repositioning is required and also uses it in later treatments where a recessive mandible is the main limiting factor of the case.

However, it can be difficult to fine tune the finish of a case when compared with an activator as vertical maxillary control is not as good as an activator unless a head gear is used. However, incisor capping is then required but this compromises the otherwise excellent aesthetics of the appliance.

It is an extremely well-tolerated, comfortable appliance which produces spectacular skeletal changes very rapidly and obviates the need for mandibular surgery in the growing patient, in most cases.

CASE REPORTS

MP presented with a skeletal Class II malocclusion. There was a Class II buccal occlusion and an 8mm overjet with a 50% overbite. The cephalometric analysis revealed a normal maxilla (SNA = 83 degrees) but a recessive mandible (SNB = 77 degrees). The maxillary length was 86mm and the mandibular length 106mm making a difference of 20mm compared to a normal value of 23mm for his age. The anterior face height was 60mm compared to a normal value of 58mm. The alignment of the teeth was good with an absence of crowding. The teeth were well located within their respective skeletal bases. The upper lip was short but the lips were potentially competent with an absence of significant mouth breathing. The patient was 11 years of age and prepubertal which indicated significant growth could be expected.

The skeletal discrepancy was considered to be well within the capabilities of modification of the dentoalveolar structures with a functional appliance. The treatment plan was to restrict maxillary A-P and vertical growth and to allow the mandible to develop normally by utilising the expected amount of mandibular growth. The eruption of all teeth, with the exception of the lower buccal teeth, was to be prevented. This would correct the overbite and utilise differential eruption of

the buccal segments to aid molar correction. The overjet was to be corrected by redirection of maxillary and mandibular growth.

An activator with a head gear was worn for eight months when an edge to edge incisor relationship was produced. After a total of twelve months treatment, fixed appliance treatment was offered but declined because the alignment of the teeth and interdigitation was satisfactory. The activator was worn as a retainer for another sixteen months and then discarded. Intraoral and facial photographs demonstrate the gross changes achieved by treatment with production of a good Class I dentition and a balanced face. The cephalometric tracings confirm these changes. The face height has increased as expected and this allowed the necessary vertical adjustments. The apparent large amount of mandibular growth is a combination of maxillary restriction and expected good mandibular growth. During the treatment period, the maxillary length increased only 1mm while the mandibular length increased by 9mm. The jaw length difference post treatment was 28mm which is now at the high end of the normal range. The face height increased to 67mm which is also at the high end of the normal range.

BD presented with a severe skeletal Class II discrepancy (SNA = 81degrees and SNB = 74 degrees). He had a steep mandibular plane angle of 29 degrees to Frankfort Horizontal compared to an average of 25 degrees. The upper face height was 62mm compared with a normal of 51mm while the lower face height was normal. BD was a mouth breather with incompetent lips. His skeletal age was 12 years at the start of treatment, suggesting good growth potential. However, the cephalometric analysis confirmed that a vertical growth pattern could be expected. This, combined with an already large upper face height, emphasised the need for vertical growth control.

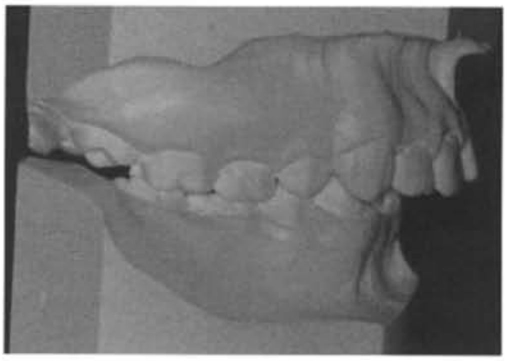
The jaw length difference was 15mm which is small compared to an average of 23mm for his age.

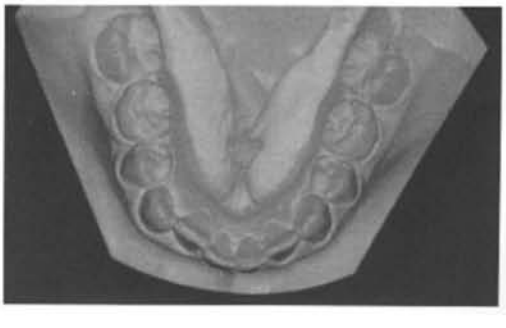
The treatment plan was to use an activator and head gear to modify the skeletal relationship but the parents were warned that clinically, mandibular surgery and maxillary impaction may be required.

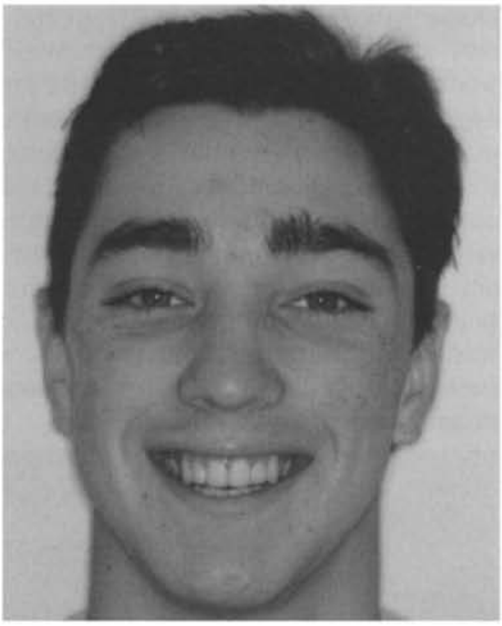
An activator, which prevented all dental eruption, and head gear were fitted and worn for thirty four months. After twelve months of functional appliance treatment the patient was offered fixed appliances to detail the occlusion but that treatment was declined. The alignment of the malposed teeth had spontaneously improved following judicious acrylic removal and labial bow adjustment.

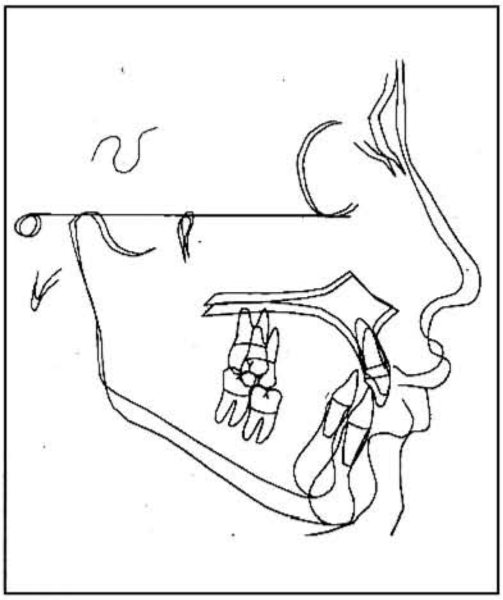
The photographs show the study models of his pretreatment condition and photographs of his dentition at the end of treatment and four years later to confirm stability. The extraoral photographs demonstrate that good lip posture and nasal respiration has been established.

The cephalometric tracing shows restriction of maxillary development and good mandibular development with a modest increase in face height. The upper face height only increased by 1mm during treatment while the lower face height increased from 64mm to 71mm. The Frankfort mandibular plane angle decreased from 29 to 28 during treatment which confirmed good vertical control. It is the combination of good vertical control and promotion of nasal respiration using a closed functional appliance that produces the good lip posture and profile seen in the post treatment photographs compared with the tracing of the soft tissues pretreatment.









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14
The Twin Block Appliance

William Clark

INTRODUCTION

The occlusal inclined plane is the functional mechanism of the natural dentition, but this fundamental force mechanism has not previously been exploited in the correction of malocclusion. Twin Blocks are designed on aesthetic principles to be more comfortable and more acceptable to the patient than any previous functional appliance.

The Twin Block technique represents a new approach to dentofacial orthopaedics. Twin Blocks use the forces of occlusion as the functional mechanism to correct the malocclusion. Twin Blocks are worn 24 hours per day. This means that the patient eats with the appliances in the mouth and the forces of mastication are harnessed to maximise the functional response to treatment.

From the patient's perspective, two factors are of prime importance when designing any type of orthodontic appliance. The fundamental objective is to provide appliances which are both comfortable and aesthetic. This principle has not always been applied to the design of functional appliances, which previously were designed in one piece to fit the teeth in both jaws.

Over the years many individual variations of the design of functional appliances have been described after the original development of the monoblock at the turn of the century by Pierre Robin (Robin, 1902). The original appliances were bulky and cumbersome and were only suitable for night time wear. Subsequent modification of design reduced the bulk of these appliances, aiming to increase day-time wear by reducing palatal acrylic and replacing some acrylic with wire components. These modifications were successful in many cases in improving patient acceptance of the appliances for day-time wear, and therefore improved the consistency of response to treatment.

Even the best of these appliances, such as those developed by (Bimler, 1977) and (Frankel 1966, 1969 & 1989) were complex, and therefore expensive to construct. The addition of wires increased the flexibility of the appliances, but at the same time they became more vulnerable to fracture or distortion, and were difficult to repair. The bionator, a one piece activator of reduced bulk, became popular as a simpler alternative.

However all of these functional appliances shared a major disadvantage. The upper and

lower components were joined together, so that the patient could not eat, speak or function normally with the appliances in the mouth. In addition some variations were not aesthetic and proved uncomfortable to wear. It was impossible to wear the appliances full time.

Twin Blocks free the patient of these restrictions. The patient can function normally in Twin Blocks, and is able to eat and speak without restriction of normal movements of the tongue, lips and mandible. This enables the appliances to be worn full time.

PROPRIOCEPTIVE STIMULUS TO GROWTH

In normal development the inclined plane mechanism plays an important part in determining the cuspal relationship of the teeth as they erupt into occlusion. A functional equilibrium is established under neurological control in response to repetitive tactile stimulus. Occlusal forces transmitted through the dentition provide a constant proprioceptive stimulus to influence the rate of growth and the trabecular structure of the supporting bone.

The proprioceptive sensory feedback mechanism controls muscular activity and provides a functional stimulus to or deterrent to the full expression of mandibular growth. When a distal occlusion develops the occlusion of the teeth represents a servo-mechanism which locks the mandible in a distally occluding functional position. Twin Blocks use occlusal inclined planes to promote protrusive function to correct the maxillo-mandibular relationship. Full time wear is crucial in achieving the optimum orthopaedic response to treatment to correct a distal occlusion.

Twin Blocks are occlusal bite blocks that are designed for full-time wear to take advantage of all functional forces applied to the dentition, including the forces of mastication. The bite blocks interlock at a 70° angle, covering the upper and lower teeth in the buccal segments. By causing a functional mandibular displacement the interlocking occlusal bite blocks are designed to alter the distribution of occlusal forces acting on the dentition to correct a malocclusion during the development of the dentition.

Twin Blocks achieve rapid functional correction of malocclusion by the transmission of favourable occlusal forces to occlusal inclined planes that cover the posterior teeth. The forces of occlusion are used as the functional mechanism to correct the malocclusion.

In comparison with other functional appliances, a number of advantages result from using separate upper and lower bite blocks. Occlusal inclined planes give greater freedom of movement in anterior and lateral excursion and cause less interference with normal function. The functional mechanism is very similar to the natural dentition. An additional motivating factor is that the appearance is noticeable improved when twin blocks are fitted and the absence of lip, cheek or tongue pads places no restriction on normal function.

The goal in developing the Twin Block approach to treatment was to produce a technique that could maximise the growth response to functional mandibular protrusion by using an appliance system that is simple, comfortable and aesthetically acceptable to the patient.

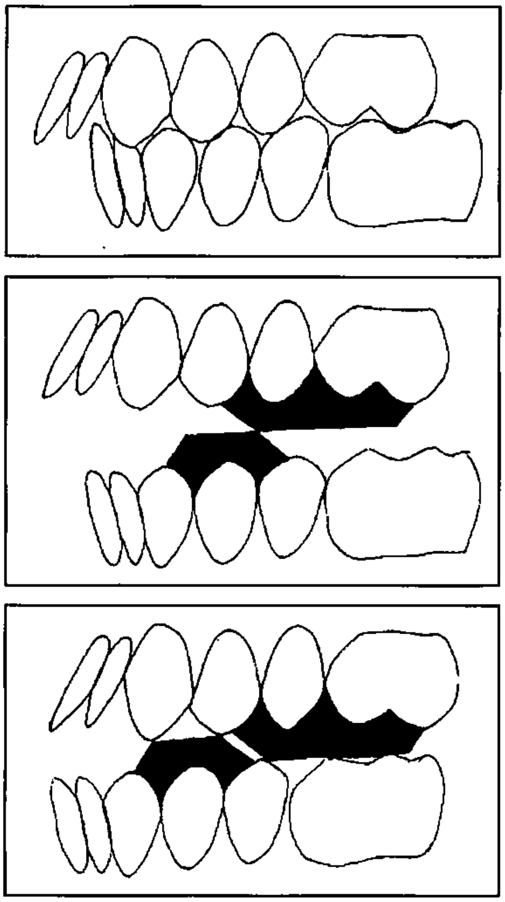


Fig. 1. Twin Blocks use the forces of occlusion to correct the malocclusion - The mandible is guided forward by the occlusal inclined plane

BITE REGISTRATION

Twin Blocks are constructed to a protrusive bite that effectively modifies the occlusal inclined plane by means of acrylic inclined planes on occlusal bite blocks. the occlusal inclined plane acts as a guiding mechanism causing the mandible to be displaced downwards and forwards. With the appliances in the mouth, the patient cannot occlude comfortably in the former distal position and the mandible is encouraged to adopt a protrusive bite with the inclined planes engaged in occlusion. The unfavourable cuspal contacts of a distal occlusion are replaced by favourable proprioceptive contacts on inclined planes of the Twin Blocks to correct the malocclusion and to free the mandible from its locked distal functional position.

In treatment of Class II Division I malocclusion with an overjet of up to 10mm the construction bite is normally taken in a forward mandibular posture to an edge-to edge position with the upper anteriors, provided the patient can comfortably maintain full occlusion on the appliances in that position. It is important to identify patients who have difficulty in maintaining an edge to edge position. This is achieved by measuring the total protrusive path of the mandible in order to assess the patient's freedom of movement in forward posture. First the overjet is measured in the fully retruded position and then in the position of maximum protrusion. The difference between these two measurements is the total protrusive path.

The position of maximum protrusion is not a physiological position and from examination of the function of the mandibular joint, indicates that the range of physiological movement of the mandible is no more than 70% of the total protrusive path. This determines that the maximum activation of a functional appliance should not exceed 70° of the total protrusive path of the mandible. The George bite gauge is a convenient instrument to register a protrusive bite because it has a sliding jig attached to a millimetre scale designed to measure the protrusive path of the mandible, and can be subsequently adjusted to record a protrusive bite of no more than 70% of the total protrusive path.

The advantage of this method of bite registration lies in identifying the patient who has a limited range of protrusive

movement, and would therefore be unable to maintain contact on the inclined planes if the activation exceeds their physiological range of movement. These patients usually exhibit a vertical growth pattern and mandibular advancement must then proceed more gradually by increments of activation. By comparison the horizontal grower will normally maintain an edge to edge incisor relationship more easily provided the overjet is not excessive.

The amount of vertical activation is also important, and is determined by two factors. First there must be adequate vertical clearance between the cusps of the upper and lower first premolars, or deciduous molars to accommodate blocks of sufficient thickness to activate the appliance. The blocks are normally 5 to 6mm thick between the first premolars. Secondly the vertical activation must open the bite beyond the free-way space to ensure that the patient cannot drop the mandible into rest position and negate the proprioceptive functional response of the inclined planes.

APPLIANCE DESIGN AND CONSTRUCTION

In the early stages of their evolution, Twin Blocks were conceived as simple removable appliances with interlocking occlusal bite blocks designed to posture the mandible forwards to achieve functional correction of a Class II Division I malocclusion. This basic principle still applies but over the years many variations in appliance design have extended to scope of the technique to treat a wide range of all classes of malocclusion. Appliance design has been improved and simplified to make Twin Blocks more acceptable to the patient without reducing efficiency.

APPLIANCE DESIGN - STANDARD TWIN BLOCKS

The Class II Division I malocclusion typically presents a narrow upper arch with the lower arch in distal occlusion. A screw is routinely included in the upper appliance for compensatory expansion in the upper arch to accommodate the lower arch as the mandible translates forward. The standard design of Twin Blocks, therefore, has provision for midline expansion. The inclined planes are positioned mesial the upper and lower first molars with the upper block covering the upper molars and second premolars or deciduous molars, and the lower blocks extending mesially from the second premolar or deciduous molar region.

To improve retention of Twin Blocks the author designed the delta clasp in 1985. (Fig 2A) A statistical comparison of 75 patients with the Delta clasp and an equivalent number with the modified arrowhead clasp (Adams, 1984) confirmed that the delta clasp had a breakage rate of 1% compared with 10% for the Adams clasp. In addition the retentive properties of the delta clasp were improved by the closed triangular or circular arrowhead.

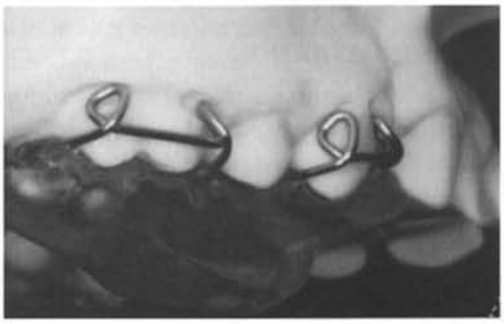


Fig. 2A Delta clasp

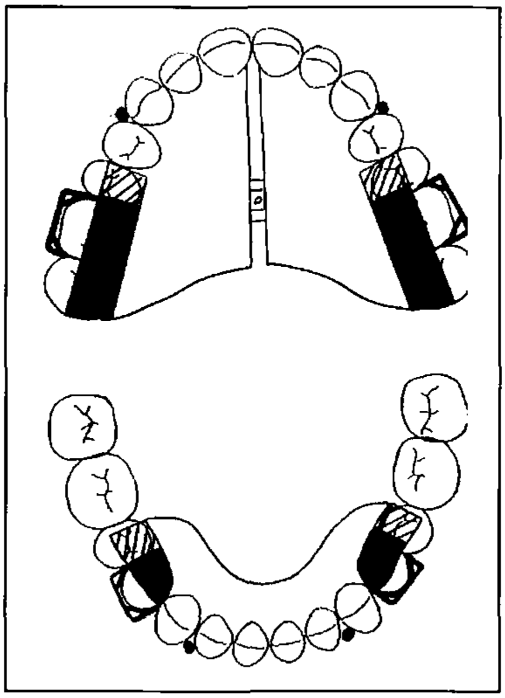


Fig. 2B Class 2 Division 1 - Permanent Dentition

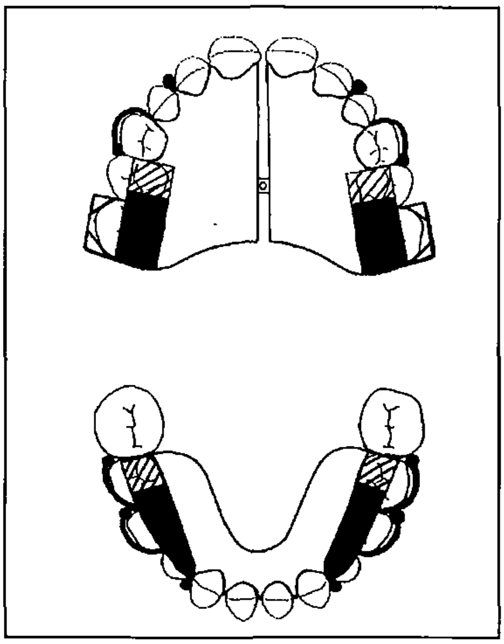


Fig. 2C Bond C-Clasps with composite to improve fixation. After first few days free clasps, leaving composite on teeth for improved retention.

The upper appliance has delta clasps on upper first molars and additional ball ended clasps may be placed interdentally distal to the canines or between the premolars or deciduous molars. The lower appliance is a simple bite block with delta clasps on the first premolars and ball clasps mesial to the canines. (Fig 2B) In mixed dentition appliance design is modified by using 'C' clasps which may be bonded to deciduous teeth to fix the appliances in the mouth temporarily for a period of 10 days. This enables the patient to adjust to wearing the appliance full time 24 hours per day during the crucial first few days with a new appliance. (Fig 2C).

MODIFICATION FOR TREATMENT OF CLASS II DIVISION 2 MALOCCLUSION

Having developed a protocol for Twin Block treatment of Class II division 1 malocclusion, attention was turned to Class II division 2 malocclusion. The original Twin Block prototype appliances were modified from the standard design for correction of Class II division 1 malocclusion by the addition of springs lingual to the upper incisors to advance retroclined upper incisors. (Fig 3A) At the same time the mandible was translated forwards to correct the distal occlusion and the appliance was trimmed to encourage eruption of the posterior teeth to reduce the overbite.

The Class II division Twin Blocks were worn for 6 months, at which stage brackets were fitted on the upper anterior teeth and activated with a sectional archwire to correct individual tooth alignment. This combination fixed/functional appliance treatment continued for 6 months. Completion of treatment was then effected with a simple upper fixed appliance. An alternative appliance design for treatment of Class II division 2 malocclusion, appliance design for

treatment of Class II division 2 malocclusion, appliance design uses sagittal screws to advance the upper anterior teeth Control of the vertical dimension is achieved by sequentially adjusting the thickness of the posterior occlusal inclined planes to control eruption (Fig 3B).

REVERSE TWIN BLOCKS

Treatment of Class III malocclusion is achieved by reversing the occlusal inclined planes to apply a forward component of force to the upper arch and a downward and distal force to the mandible in the lower molar region. The inclined planes are set at 70° to the occlusal plane with bite blocks covering lower molars and upper deciduous molars or premolars, with sagittal screws to advance the upper incisors (Fig 4).

ANGULATION OF THE INCLINED PLANES

During the evolution of the technique, the angulation of the inclined plane has varied form 90° to 45° to the occlusal plane, before arriving at an angle of 70° to the occlusal plane as the final compromise angle that proved most suitable in the majority of cases.

As previously stated, the earliest Twin Block appliances were constructed with bite blocks that articulated at a 90° angle, so that the patient had to make a conscious effort to occlude in a forward position. However, some patients had difficulty maintaining a forward posture and, therefore, would revert to retruding the mandible back to its old distal occlusion position, occluding the bite blocks together on top of each other on their flat occlusal surfaces. This was detectable at an

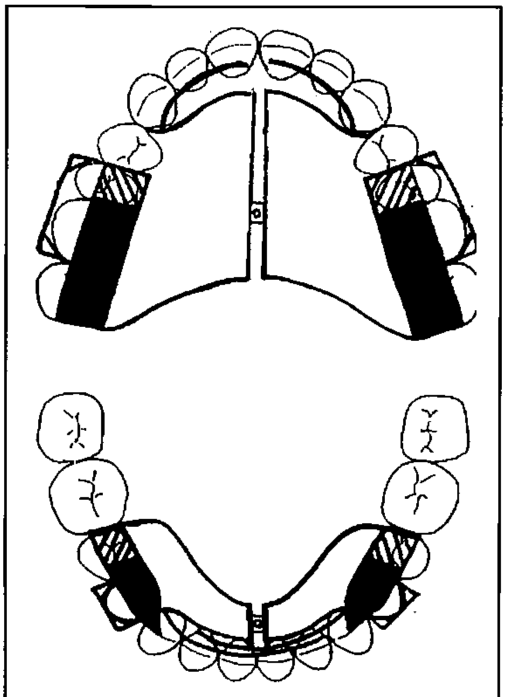


Figure 3A

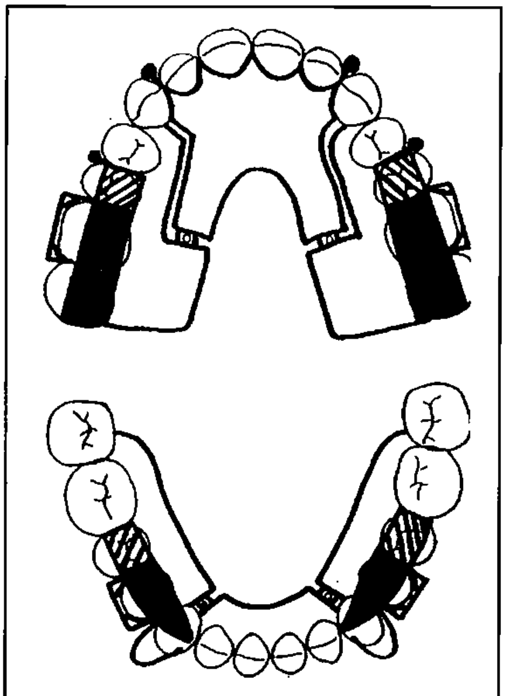


Figure 3B

Fig. 3. A and B (diagrams-Correction of Class II Division 2 malocclusion by advancing the mandible and proclining the upper incisors with springs or sagittal screws)

early stage of treatment when in could be observed that the patient was not posturing forwards consistently. A significant posterior open bite was caused by biting on the blocks in this fashion. This complication was experienced in approximately 30% of the earliest Twin Block cases. It was resolved by altering the angulation of the bite blocks to 45° to the occlusal plane in order to guide the mandible forwards. This was immediately successful in eliminating the problem.

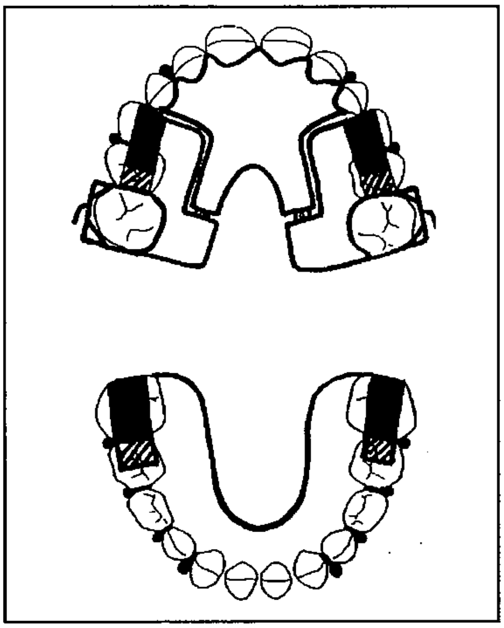


Fig. 4. (diagram - Reverse Twin Blocks for correction of Class III malocclusion with sagittal screws to advance upper incisors)

An angle of 45° to the occlusal plane applies an equal downward and forward component of force to the lower dentition. The direction of occlusal force on the inclined planes encourages a corresponding downward and forward stimulus to growth. After using a 45° angle on the blocks for eight years, the angulation was finally changed to the steeper angle of 70° to the occlusal plane to apply a more horizontal component of force. It was reasoned that this may encourage more forward mandibular growth. If the patient as any difficulty in posturing forwards, this is a sign that the activation should be reduced by trimming the inclined planes to reduce the amount of mandibular protrusion. It then becomes much easier for the patient to maintain a forward posture.

BITE REGISTRATION

The Exactobite or Projet Bite Gauge (the name differs in the USA and Britain) is designed to record a protrusive interocclusal record or 'bite registration' in wax for construction of Twin Blocks. Typically, in a growing child, an overjet of up to 10mm can be corrected on the initial activation by registering an incisal edge - to - edge bite with 2mm interincisal clearance. This is provided that the patient can comfortably tolerate the mandible being protruded so that the upper and lower incisors align vertically edge to edge. Larger overjets invariably require partial correction, followed by reactivation after the initial partial correction is accomplished.

THE TWIN BLOCK TECHNIQUE - STAGES OF TREATMENT

Twin Block treatment is described in two stages. Twin Blocks are used in the active phase to correct the anteroposterior relationship and establish the correct vertical dimension. Once this phase is accomplished, the Twin Blocks are replaced with an upper Hawley type of appliance with an anterior inclined plane, which is then used to support the corrected position as the posterior teeth settle fully into occlusion.

Stage 1:active phase

Twin Blocks achieve rapid functional correction of mandibular position from ta skeletally retruded Class II to Class I

occlusion using occlusal inclined planes over the posterior teeth to guide the mandible into correct relationship with the maxilla. In all functional therapy, sagittal correction is acheived before verticle development of the posterior teeth is complete. The verticle dimension is controlled first by adjustment of the occlusal bite blocks, followed by use of the previously mentioned upper inclined plane appliance.

In treatment of deep overbite, the bite blocks are trimmed selectively to encourage eruption of lower posterior teeth to increase the vertical dimension and level the occlusal plane (Fig 5A & B).

The upper block is trimmed occlusodistally to leave the lower molars 1-2 mm clear of the occlusion to encourage lower molar eruption and reduce the overbite. By maintaining a minimal clearance between the upper bite block and the lower molars the tongue is prevented from spreading laterally between the teeth. This allows the moars to erupt more quickly. At each subsequent visit the upper bite block is reduced progressively to clear the occlusion with the lower molars to allow these teeth to erupt, until finally all the acrylic has been removed over the occlusal surface of the upper molars allowing the lower molars to erupt fully into occlusion.

Throughout this trimming sequence it is important not to reduce the leading edge of the inclined plane, so that adequate functional occlusal support is given until a three point occlusal contact is achieved with the molars in occlusion.

Conversely, in treatment of anterior open bite and verticle growth patterns, the posterior bite blocks remain unreduced and intact throughout treatment. This results in an intrusive effect on the posterior teeth, while the anterior teeth remain free to erupt, which helps to increase the overbite and bring the anterior teeth into occlusion. (Fig. 6A, B & C)

At the end of the active stage of Twin Block treatment the aim is to achieve correction to Class 1 occlusion and control of the vertical dimension by a three point occlusal contact with the incisors and molars in occlusion. At this stage the overjet, overbite and distal occlusion should now be fully corrected.

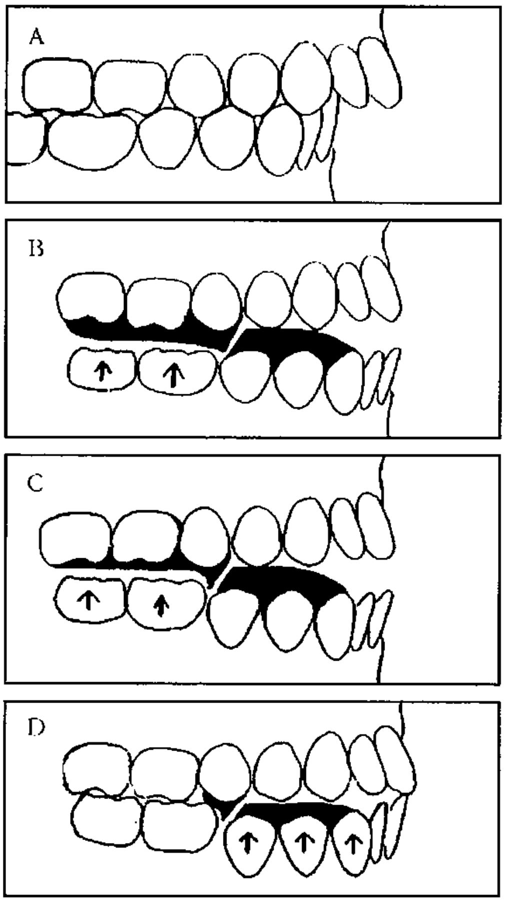


Fig. 5 Sequence of trimming blocks to reduce deep overbite.

A - Before treatment - Increased overjet and overbite full unit distal occlusion

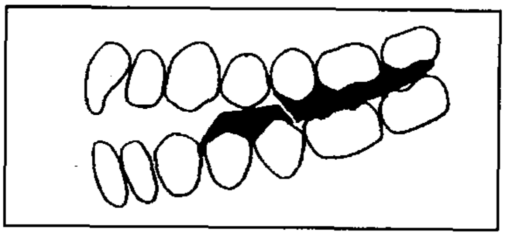
B - Twin blocks activated to edge, edge to edge position, slightly open, usually 2mms. Trim upper block occluso distally to allow eruption of lower molars.

C - Progressive trimming clears the upper block from occlusion to allow lower molars to erupt.

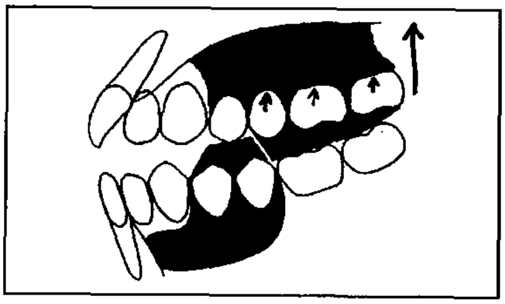
D - When molars are in occlusion and incisors are edge to edge, trim lower block occlusally in the premolar region to allow lower premolars to erupt. It is essential to retain the inclined plane contact.

In reduced overbite cases

Cover all posterior teeth to prevent eruption



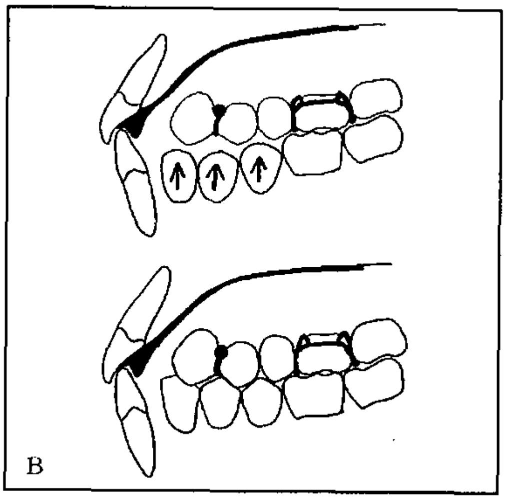
Apply high pull traction to intrude upper posterior teeth



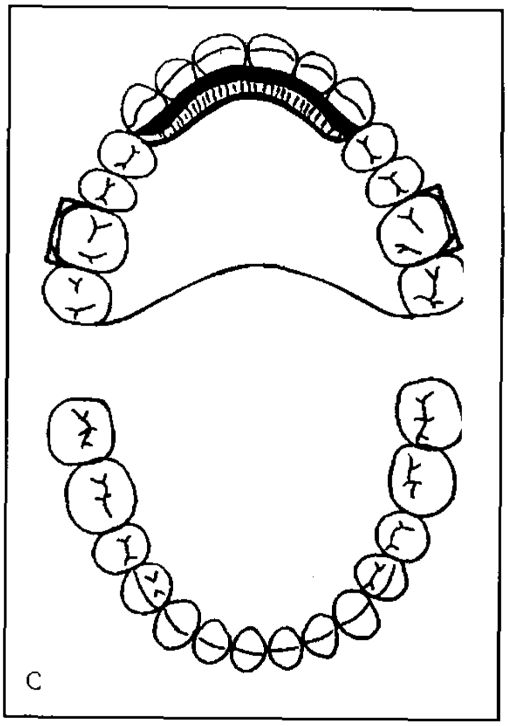
Trim acrylic clear lingual to anterior teeth - to encourage eruption and to increase overbite

Fig. 6. A - Maintain posterior cover to intrude posterior teeth to intrude posterior teeth and reduce anterior open bite

Anterior guide plane



Supports corrected occlusion - Lower premolars are free to erupt



To enlarge lingual to lower incisors and cannines

Fig. 6. B and C (diagram - Support phase - anterior inclined plane)

Stage 2: support phase

The aim of the support phase is to maintain the corrected incisor relationship until the buccal segment occlusion is fully interdigitated. To achieve this objective an upper removable appliance is fitted with an anterior inclined plane to engage the lower incisors and canines (Fig 6B & C).

The lower Twin block appliance is left out at this stage and the removal of posterior bite blocks allows the posterior teeth to erupt. Full-time appliance wear is necessary to allow time for internal bony remodelling to support the corrected occlusion as the buccal segments settle fully into occlusion.

Retention

Treatment is followed by retention with the upper anterior inclined plane appliance. Appliance wear is reduced to night time only when the occlusion is fully established. A good buccal segment occlusion is the cornerstone of stability after correction of arch-to-arch relationships. The appliance-effected advanced mandibular position will not be stable until the functional support of a full buccal segment occlusion is well established.

TIMETABLE OF TREATMENT

Average treatment time

- *Active phase*: average time 6-9 months to achieve full reduction of overjet to a normal incisor relationship and to correct the distal occlusion.
- *Support phase*: 3-6 months for molars to erupt into occlusion and for premolars to erupt after trimming the blocks. The objective is to support the corrected mandibular position after active mandibular translation while the buccal teeth settle fully into occlusion.
- *Retention*: 9 months, reducing appliance wear when the position is stabilised.

An average estimate of treatment is 18 months, including retention.

Response to treatment

Rapid improvements in facial appearance are seen consistently even during the first few months of Twin Block treatment. These changes are characterised by the development of a lip seal and a noticeable improvement in facial balance and harmony. In growing children, the facial muscles adapt very quickly to an altered pattern of occlusal function. The changes in appearance are so significant that the patients themselves frequently comment on the improvement in the early stages of treatment.

The facial changes are soon accompanied by equivalent dental changes and it is routine to observe correction of a full unit distal occlusion within the first six months of treatment. The response to treatment is noticeably faster compared with alternative functional appliances since the twin block is worn during eating.

ADVANTAGES OF TWIN BLOCKS

The Twin Block is the most comfortable, the most aesthetic and the most efficient of all the functional appliances. Twin Blocks have many advantages compared with other functional appliances.

- *Comfort*: Patients wear Twin Blocks 24 hours per day and can eat comfortably with the appliances in place.
- *Aesthetics*: Twin Blocks can be designed with no visible anterior wires without losing efficiency in correction of arch relationships.
- *Function*: The occlusal inclined plane is the most natural of all the functional mechanisms. There is less interference with normal function because the mandible can move freely in anterior and lateral excursion without being restricted by a bulky one-piece appliance.
- *Patient compliance:* Twin blocks may be fixed to the teeth temporarily or permanently to guarantee patient compliance. Removable twin blocks can be fixed in the mouth for the first week or 10 days of treatment to ensure that the patient adapts fully to wearing twin blocks 24 hours per day.

- *Facial appearance:* From the moment twin blocks are fitted the appearance is noticeably improved. The absence of lip, cheek or tongue pads, as used in some other appliances, places no restriction on normal function, and does not distort the patient's facial appearance during treatment. Improvements in facial balance are seen progressively in the first 3 months of treatment.
- *Speech:* Patients can learn to speak normally with twin blocks. In comparison with other functional appliances, twin blocks do not distort speech by restricting movement of the tongue, lips or mandible.
- *Clinical management:* Adjustment and activation is simple. The appliances are robust and not prone to breakage. Chairside time is reduced in achieving major orthopaedic correction.
- *Arch development:* Twin blocks allow independent control of upper and lower archwidth. Appliance design is easily modified for transverse and sagittal arch development.
- *Mandibular repositioning:* Full-time wear consistently achieves rapid mandibular repositioning that remains stable out of retention.
- *Vertical control:* Twin blocks achieve excellent control of the vertical dimension in treatment of deep overbite and anterior open bite. Vertical control is significantly improved by full-time wear.
- *Facial asymmetry:* Asymmetrical activation corrects facial and dental asymmetry in the growing child.
- *Safety:* Twin blocks can be worn during sports activities with the exception of swimming and violent contact sports. Then they may be removed for safety.
- *Efficiency:* Twin blocks achieve more rapid correction of malocclusion compared to one-piece functional appliances because they are worn full time. This benefits patients in all age groups.
- *Age of treatment:* Arch relationships can be corrected from early childhood to adulthood. However, treatment is slower in adults and the response is less predictable.
- *Integration with fixed appliances:* Integration with conventional fixed appliances is simpler than with any other functional appliance. In combined techniques, twin blocks can be used to maximise the skeletal correction while fixed appliance are used to detail the occlusion, because twin blocks need have no anterior wires, brackets can be placed on the anterior teeth to correct tooth alignment simultaneously with correction of arch relationships during the orthopaedic phase. During the support phase an easy transition can be made to fixed appliances.
- *Treatment of temporomandibular joint dysfunction:* The twin block may at times also be used as an effective splint in treatment of patients who present temporomandibular joint dysfunction due to displacement of the condyle distil to the articular disc. Full-time wear allows the disc to be recaptured, when disc reduction is possible in early stage TMJ problems, and at the same time sagittal, vertical and transverse arch development proceeds to eliminate unfavourable occlusal contacts.

CASE REPORT

A

B

C

D

E

F

G

H

J

K

L

M

N

O

P

Q

R

S

Fig. 7. W.L. - Age 10 years and 3 months

A & B - Facial appearance before treatment

C, D & E - Occlusion before treatment

F, G & H - Occlusion after 12 months treatment

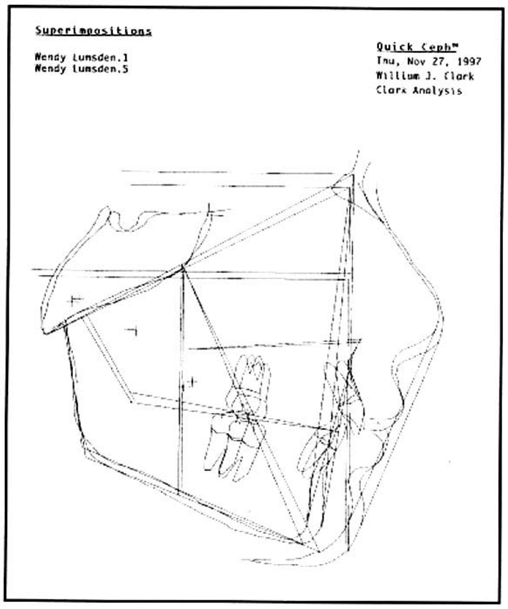
J & K - Facial appearance after 12 months treatment at age 11 years and 6 months

L, M & N - Occlusion on completion of 18 months treatment

O, P & Q - 4 years out of retention at age 16 years and 1 month

R & S - Upper and lower archform at age 16 years and 1 month

Analysis Clark		1	Norm	Clin. Dev.		2	5
Sketetal Angles							
Cranial Base Angle	(dg)	26.7	27.2	-0.2		27.9	28.4
Mandibular Plane	(dg)	23.2	25.4	-0.5		24.3	21.4
Cranio-Mandibular An	(dg)	49.8	53.4	-1.2	*	52.5	49.8
Facial Plane Angle	(dg)	-6.6	-2.9	-1.2	*	-5.8	-4.3
Facial Axis Angle	(dg)	24.3	27.3	-1.0		25.3	26.4
Condyle Axis Angle	(dg)	29.8	27.0	0.9		30.3	31.5
Max Plane Angle	(dg)	3.2	0.6	0.9		3.6	3.8
Occlusal Plane Angle	(dg)	10.0	12.0	-1.0		11.8	7.5
Dental Angles							
U-Incisor/Vertical	(dg)	33.3	24.0	1.5	*	22.1	15.0
L-Incisor/Vertical	(dg)	34.3	26.0	1.7	*	42.2	35.8
Inter-incisal Angle	(dg)	114.7	130.0	-2.5	**	116.8	130.4
Sketetal Relations							
Convexity	(mm)	7.7	1.6	3.0	***	6.2	5.0
Mx Position to Na/V	(mm)	0.4	-2.4	1.1	*	-0.6	0.1
Chin Position	(mm)	-13.3	-8.4	-1.6	*	-12.2	-9.1
Ant Cranial Base	(mm)	56.6	51.0	5.6	***	59.2	58.4
Porion Location	(mm)	-49.9	-38.6	-5.1	***	-50.7	-51.6
Dental Relations							
Mx1 to A-I FH	(mm)	5.1	1.2	1.4	*	2.7	2.2
L/Incisor to A-Po	(mm)	0.4	1.0	-0.2		3.1	1.4
Mx 6 to PTV	(mm)	15.0	13.3	0.6		14.6	18.0
Incisor Overjet	(mm)	9.3	2.5	2.7	**	4.0	4.7
Incisor Overbite	(mm)	3.0	2.5	0.3		0.7	3.5
Molar Relation	(mm)	3.3	-3.0	6.3	***	-0.4	0.1
Esthetic Relations							
Lower Lip E-Plane	(mm)	0.4	-2.0	1.2	*	-0.2	-2.9
Facial Proportions							
Post Facial Height	(mm)	67.3	54.8	3.8	***	69.2	71.1
Upper Facial Height	(mm)	53.5	48.0	2.8	**	56.9	56.8
Lower Facial Height	(mm)	65.6	58.3	2.1	**	68.5	68.4
Midfacial Length	(mm)	95.9	80.4	4.8	***	97.7	97.9
Mandibular Length	(mm)	109.1	99.7	2.3	**	113.5	115.2
Maxillomand. Diff.		13.2	19.3	-2.4	**	15.8	17.3
Ramus Height	(mm)	43.4	44.0	-0.1		45.1	46.4
Corpus Length	(mm)	77.8	71.2	6.6	***	77.9	78.8
S-N	(mm)	76.5	75.7	0.3		79.0	81.5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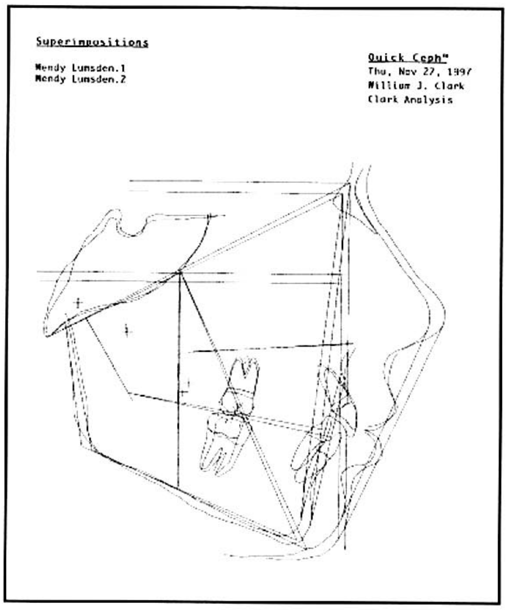
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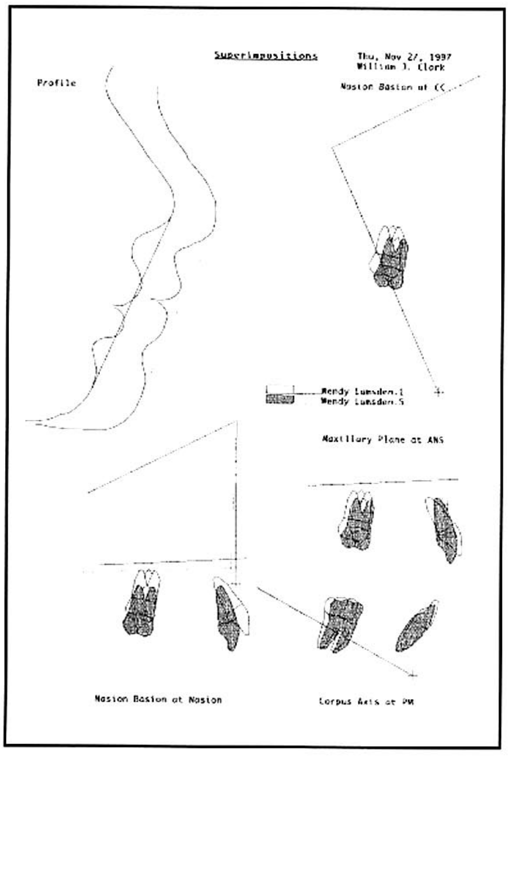
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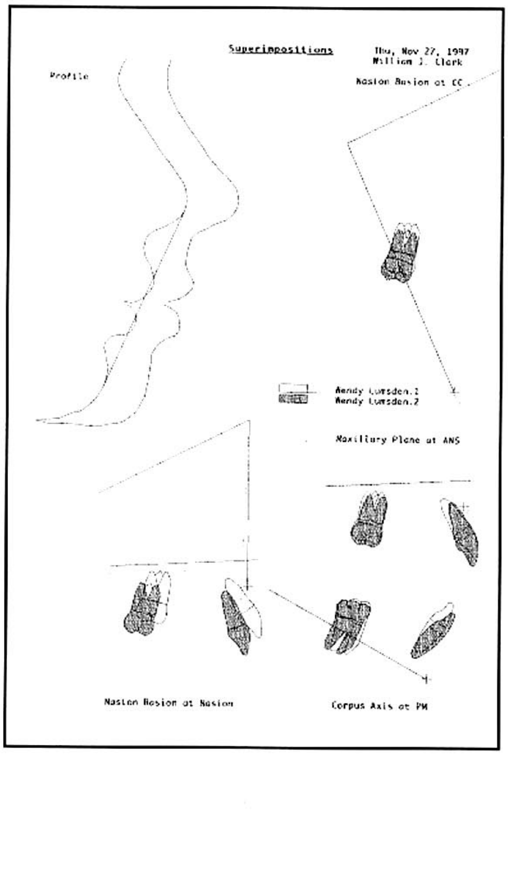
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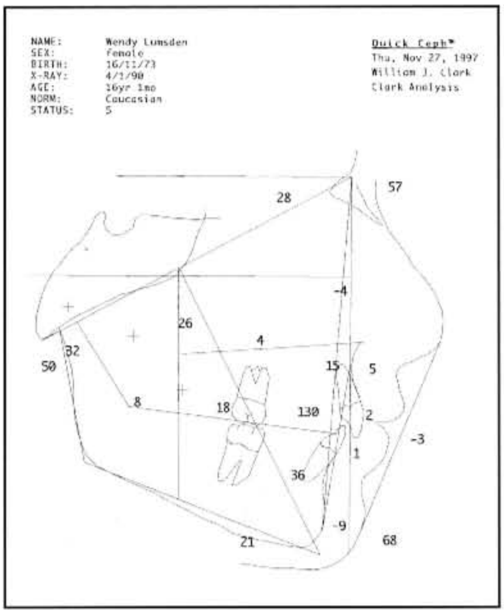

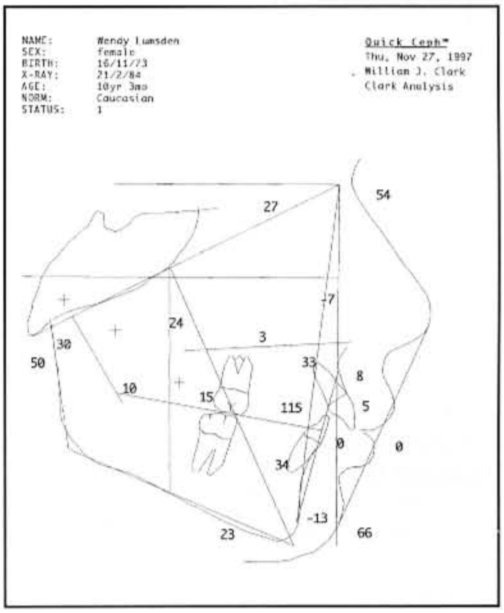

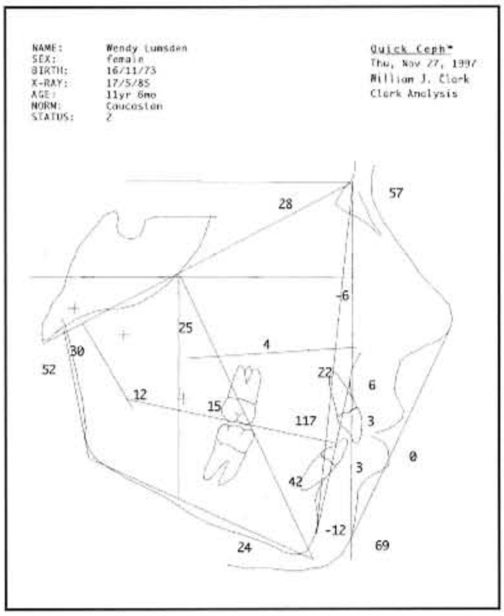

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15
Biology of Tooth Movement

Tony Collett

INTRODUCTION

Orthodontic therapy aims at moving teeth and/or modifying the growth of the jaws. While there is great controversy over the ability to achieve the latter, there is certainly no doubt that the former is the basis of our discipline. Those engaged in the practice of orthodontics require not only a strong grasp of the mechanics of therapy, but should also have a sound knowledge of the underlying principles. It is only by acquiring such knowledge that one is able to fully and critically evaluate new developments in the field. The periodontal ligament is a modified periosteum with the potential to mediate bone resorption and formation. An intact and viable ligament is essential for orthodontic tooth movement. As expected, ankylosed teeth and healthy osseointegrated implants do not move in response to orthodontic force. The opportunity exists for osseointegrated implants to be used to supplement anchorage in orthodontic treatment, the implant constituting true osseous anchorage.

In the discussion below, a brief outline of previous thoughts on mechanisms relating to the behaviour of bone is provided. These historical views, the pressure-tension hypothesis and "panty-hose" theory, have been pushed into the background with the elucidation of biochemical pathways and findings from the field of molecular biology.

HISTORICAL PERSPECTIVE

Hunter, in the 18th century (Davidovitch, 1991) wrote "to extract an irregular tooth would answer but little purpose, if no alterations could be made in the situation of the rest; but we find that the very principle upon which teeth are made to grow irregularly is capable, if properly directed, of bringing them even again. This principle is the power which many parts (especially bones) have of moving out of the way of mechanical pressure." Delabbare, in 1815, noted that pain and swelling of the paradental tissues occurs in response to orthodontic force application. Later that century Farrer suggested orthodontic tooth movement is mediated partly by the bending of alveolar bone.

It has long been recognised that bones adapt by remodelling to best withstand the functional forces imposed on them. This knowledge has enabled the use of force to modify body growth. Perez-Martinez (1960) observed cranial expansion in Columbian Indians. The direction of cranial expansion

had been influenced by the position of boards or bandages bound around the heads of the Indians when they were young children.

During the late 19th century a concept of skeletal plasticity and dependence of organisation on the functional environment was established. In 1862 Heuter and Volkmann noted that relatively greater growth of bone occurred under diminished compression, and that abnormal differences of compression caused unequal, asymmetrical growth of a joint. This became known as the Heuter-Volkmann theory that compression inhibits bone growth and produces atrophy, while tension increases bone growth. This theory laid the foundation for the pressure-tension hypothesis.

Julius Wolff refuted this theory and suggested that both compression and tension lead to the formation of osseous tissue which adapts its form to remain in balance with the functional environment. Wolff published his "Law of the Transformation of Bone" in 1892, this being: *Every change in the form and function of bones or of their function alone is followed by certain definite changes in the internal architecture and equally definite secondary alterations in their external conformation in accordance with mathematical laws.*

At this time bones were considered to function purely as static weight bearers and many attempts were made to analyse the architecture of bones in this light. Hermann Meyer pointed out the correlation between the architecture of cancellous bone and the mechanical stressing to which it is subjected during function.

The arrangement of the trabeculae can be well appreciated in the famous anecdote concerning the great engineer, Professor Culmann of Zurich. Legend has it that back in 1866 Culmann wandered into Meyer's dissecting room, where a section of bone was being contemplated. Up went the cry of "That's my crane!" as Culmann recognised the bony trabeculae of the head of the femur were in arrangement similar to the lines of compression and tension of the crane he was designing.

There are many examples of unwanted skeletal changes caused by repetitive intermittent forces on bones as a result of customs or occupations for example, "Lamp lighter's thumb", a condition associated with "mushrooming" of the first phalanx from repeated thrusts against a stop-cock (Kennedy, 1934). Skeletal changes have been described in Aztec Indians (Atkinson, 1966), who from an early age, carried heavy loads on their backs, suspended by a band around their forehead. A new occupational hazard of the modern technological era is the effect of prolonged spaceflight on bone architecture. Spaceflight has been shown to induce a negative calcium balance and osteopaenia. Rats that had spent five days in orbit aboard the Soviet COSMOS 1514 biologic satellite exhibited bone effects due to weightlessness such as an increase in the number of osteoclasts per unit area of the trabecular surface (Vico *et al.*, 1987). It was postulated that a stimulation of bone resorption activity occurs in the trabeculae of unloaded bones during the early phase of spaceflight.

For a fascinating dissertation of historical interest the reader is referred to the work by Darcy Thompson, *On Growth and Form.*

Pressure-Tension Hypothesis

The pressure-tension hypothesis, as described by early workers (Oppenhein, 1911; Schwarz, 1932), proposed that pressure resulting from movement of the tooth in the periodontal space caused resorption while tension caused formation; a vital periodontal ligament being a prerequisite.

The pressure-tension hypothesis was then later restated to link pressure with bone formation and tension with resorption (Bassett, 1971). However, studies of tooth movement (Storey, 1981) and rat tail vertebrae (Storey and Feik, 1982; Pollard *et al.*, 1984) suggest that bone forms under tension and resorbs under pressure.

Earlier studies had also led to the conclusion that bone forms under tension and resorbs under pressure. Glucksmann (1942) implanted embryonic femora, tibiae, metatarsals and phalanges from 4 to 12 day chick embryos, between a pair of 17 day embryonic ribs in culture. The ribs, which were connected by intercostal muscles, gradually drew together during cultivation, thus exerting pressure on the skeletal rudiment. Skeletal rudiments were observed to respond by reorientation of cells and alteration in form consistant with the pressure tension hypothesis.

Ackerman *et al.*, (1966) investigated the effect of pressure on the bones of the sternum of pigeons. A series of paired magnets were placed on each side of the sternum, and the results indicated that a low pressure applied for a long period of time caused more resorption than high pressure applied for a short time. These authors concluded that the duration of pressure application was a more important factor in regard to bone resorption than the absolute amount.

The findings in these studies are consistent with the hypothesis that pressure induces resorption of bones and tension induces formation. There are some obvious anomalies to this concept, such as the compression of teeth by masticatory forces without alveolar bone resorption, and compression of plantar surface of the os calcis while walking without a net change in bone quantity (Epker and Frost, 1965).

In addition, experimental evidence is also inconsistent with pressure inducing resorption and tension inducing formation. Gelbke (1951) encircled the distal epiphyseal plates of canine femora with wire loops. He found that a permanent degree of pressure inhibits longitudinal growth of bone and does not lead to a compensatory decrease in girth of the bone. The inhibition of growth was due to the prevention of proliferation in the growth cartilage, which narrowed and became irregular in its arrangement. Replacement of existing cartilage proceeded without any interruption. Bone atrophy did not occur. Gelbke also found that permanent tension did not increase endochondral bone growth. On the contrary, it had the same effect as compression. If both the pressure and tension were removed from the bone before skeletal maturation the effects of the forces appeared to be reversible.

Liskova and Hert (1971), and Hert *et al.*, (1971) compiled experimental evidence indicating that the distinction between compression and tension might be irrelevant. Rabbit tibiae were transfixed by Kirschner wires which emerged through the skin, and were connected to electromagnets to allow either proximation or distraction of the wires. These workers found that neither compression nor tension affected the response of cellular periosteum.

The Periosteum's Role

It has been proposed (Storey and Feik, 1982) that the general shape of a simple tubular bone is maintained during growth by three factors: first, the longitudinal and lateral growth of the endochondral cartilage; second, periosteal tensions inducing circumferential expansion of the diaphysis; and third, the contraction of the newly formed periosteal envelope around the metaphysis

that, like a "panty-hose", induces pressure stimulating resorption to produce the inwaisting characteristics of so many long bones.

The third factor is known as Storey's "Panty-Hose" theory of bone growth (Storey, 1981). This theory presumed that the periosteal envelope plays a major role in moulding growing bones through its inherent tensile properties, and by its ability to transfer both tensile and compressive forces to the osteogenic layer of cells at the bone surface, with resultant stimulation for remodelling. As a bone grows, new bone forms where it is protected from the pressure of the tissues by the periosteal envelope.

In mature bone the periosteum still plays a decisive role in the maintenance of bone through its semi-elastic nature, transferring functional pressures and tensions to the osteogenic layers, thus stimulating remodelling. The potential for functional remodelling of bones remains throughout life but decreases with age. This is illustrated by the straightening of malaligned fractures. Every time a malaligned bone is flexed under pressure it moves away from its periosteal matrix on the pressure side and stretches the periosteum on the tension side. This induces tension on the osteogenic cells on the pressure side, stimulating bone formation and compression on the cells on the tension side, thus inducing resorption (Storey, 1981).

The effects of the periosteum on the endochondral cartilage growth plates was investigated by Lacroix (1951). Tension produced by the periosteum was found to be maximal at the epiphyseal site of attachment and greatest at the fastest growing plate. The tension produces pressure on the growth plates inhibiting the proliferation of chondrocytes. Crilly (1972) concurred with Lacroix, based on his work on the radii of young chickens.

It has been shown that circumferential division of the periosteum of transplanted rat humeri results in an overgrowth of the bone by approximately 30% (Harkness and Trotter, 1978). The periosteum appeared to spring apart when it was divided circumferentially, supporting the hypothesis that the longitudinal fibres of the periosteum are under tension, and that release of this tension allows increased growth in length. However it is not clear whether the tension in the periosteum is due solely to the activity of the growth plates, or whether it arises from other sources, such as the inserting muscles.

MODELLING AND REMODELLING OF BONE

The reader is also referred to Roberts (1994). Modelling and remodelling are the means by which trabecular and cortical bone grow, adapt and turnover.

Bone modelling is a process where resorption and formation occur at separate sites thus producing a change in the size and/or shape of the bone. In contrast, bone remodelling involves a coupling of the resorption and formation processes to replace bone. Orthodontic tooth movement consists of both modelling and remodelling events within alveolar bone. Facial growth, and responses to headgear and rapid palatal expansion involve bone modelling. Modelling is also under some control by means of hormones, during growth and ageing.

Bone turnover is by means of constant remodelling. Bone formation and resorption is linked by a series of biochemical mediators, as outlined below. Remodelling is also under the influence of hormones which affect the rate of bone turnover (Table 1). Alveolar bone remodels at a rate of 20% to 30% per year, compared to cortical bone, where the rate is 2% to 10%. This variation is made

use of in orthodontics with the concept of cortical anchorage.

In assessing patients for orthodontic treatment attention should be paid to pathology and how any conditions will impact on bone turnover. The orthodontist should liaise with the patient's medical practitioner in such situations. In cases of bone disease the formation process may lag well behind resorption, compromising the viability of the dentition.

The Periodontal Ligament

Orthodontic tooth movement can be divided into three components (Roberts, 1994), these being the initial strain, lag phase and progressive tooth movement. Initial tooth displacement occurs almost immediately. The initial response depends on periodontal ligament width, root length, anatomical configuration, force magnitude, occlusion and the periodontal status.

Displacement of the tooth halts after about a week, presumably due to periodontal ligament necrosis or hyalinisation. The lag phase is variable and this is probably attributable to factors such as age, bone density, and the extent of periodontal ligament necrosis. Progressive tooth movement then occurs with resorption (modelling and remodelling) of bone ahead of the tooth allowing for more rapid movement. Surface modelling of bone involves resorption at the periodontal ligament bone interface and formation at the trailing aspect. Resorption cavities (remodelling) ahead of the tooth decrease the bone density facilitating movement. The slower rate of tooth movement often seen in uncooperative patients where treatment mechanics are not maintained may result from the filling in of the resorption cavities with new bone.

Tooth movement appears to be proportional to the time over which the force is applied. A variable to consider with regard to intermittent forces is the circadian rhythm of periodontal ligament cell proliferation and differentiation (Roberts, 1994). Experimental evidence suggests that maximal cell proliferation coincides with the night sleeping hours.

Bone Types

An overview of bone types has been presented by Roberts (1994).

Woven bone is usually the first bone formed in response to orthodontic force application. This immature bone is not well organised and of low mineral content and hence, is relatively weak.

Lamellar bone accounts for virtually all of the adult skeleton. It is well organised, of high mineral content and strong. Lamellar bone requires many months to reach its maximum strength, an aspect that should be borne in mind when considering retention protocols.

Lamellar bone laid down within a woven bone network provides a means of achieving reasonably strong bone in a short time; such bone is known as composite bone and is usually that present during the initial period of orthodontic retention.

Another variation of lamellar bone is seen in association with ligaments and tendons; bundle bone. Bundle bone can be identified adjacent to the periodontal ligament.

Bone Quality and Tooth Movement

The density of bone together with the cross section of roots in the line of movement determine the resistance to movement, or anchorage. Anchorage depends thus not only on the amount of bone, but the quality of the bone. Orthodontists are very familiar with the fact that maxillary molars are easier to protract than mandibular molars and all have

been frustrated attempting to close the lower E-spaces in cases of congenitally missing second premolars. The mandible has more coarse trabeculae and thicker cortical plates. An additional factor contributing to the difficulty of tooth movement in the mandible may relate to the lower turnover of this dense bone.

The rate of tooth movement in the first few months is generally more rapid and then slows somewhat. Teeth move faster in growing children with, under optimum conditions, maxillary molar root movement being approximately 2 mm per month (Roberts, 1994). In adults maxillary molar movement approximates 1 mm per month. The more slowly moving lower molars translate at a rate of approximately 0.7 mm per month in children and 0.3 mm per month in adults. These differences between children and adults reflect the less dense bone and higher bone turnover (remodelling) in children.

Osteoclasts and Osteoblasts

There exists general agreement that osteoclasts are derived from the haemopoietic stem cell and should be included in the haemopoietic stem cell family (Burger and Nijweide, 1991). The link of the osteoclast lineage with the mononuclear phagocyte pathway still requires elucidation. Most likely any ties relate to very early stages of cellular differentiation, and not to mature cells. Osteoblasts are derived from ectomesenchyme.

Osteoclasts are large multinucleated cells and are the main bone resorbing cells. Osteoclasts are blood borne in contrast to osteoblasts. Bone resorption by osteoclasts results from production of proteolytic enzymes and hydrogen ions; these ions provide an optimal environment for the enzymes to degrade the bone matrix (see Martin and Ng, 1994; Mundy, 1995). While some evidence suggests the surface of the bone to be resorbed is prepared for the osteoclast by collagenase released by osteoblasts, other studies indicate osteoclasts in isolation can effect bone resorption.

Within hours of the application of an orthodontic force, increased numbers of osteoclasts appear in areas where the periodontal ligament is narrowed by displacement of the alveolus (Roberts and Ferguson, 1989). The localised response of the bone involves control mechanisms such as cytochemical messages, chemotaxis and stress generated potentials. Although the effector cell of bone resorption is the osteoclast (for a review see Martin and Ng, 1994; Vaes, 1988), studies showing that osteoblasts and not osteoclasts possess receptors for various chemical mediators indicates that osteoclast recruitment and activity involves cells of the osteoblast lineage. Thus osteoblasts may not be merely bone forming cells, but may present resorptive signals to osteoclasts or their precursor cells. There may be a subpopulation of "helper" osteoblasts which serve to regulate bone resorption, or alternatively all osteoblasts may possess the ability to act as helper cells (Meikle *et al.*, 1989). There is also some indication that stimulation of osteoclast formation by osteoblasts is dependent on cell contact (Martin and Ng, 1994). It has been observed that the relative number of preosteoblasts is greater along resorbing surfaces compared to bone forming surfaces (Roberts and Ferguson. 1989). This paradox most likely results from an arrest of osteoblast production, and thus accumulation of preosteoblasts. The high number of preosteoblasts may be an important factor in the rapid osteogenic response of the peri-

odontal ligament to orthodontic loading. Another point supporting such a role for osteoblasts is they appear to have a greater complement of receptors to biochemical mediators.

Osteoblasts are derived from the stromal cell system. The osteoblast group includes mature osteoblasts which produce the bone matrix proteins (Type 1 collagen and osteocalcin), osteocytes which are buried within the bone and communicate via canaliculi, and the bone surface lining cells. Osteoblasts are also capable of mineralising recently formed bone matrix. As mentioned above, it seems probable that osteoblasts also play a role in bone resorption.

Osteoblastic bone formation involves chemotaxis, proliferation, cell differentiation and formation of mineralised bone (Mundy, 1995). Finally, there must be cessation of osteoblastic activity. Potential mediators of chemotaxis include transforming growth factor β (TGFβ) and platelet derived growth factor (PDGF). Possible mediators of osteoblast proliferation are TGFβ I and II, PDGF, insulin-like growth factors (IGF) I and II and heparin-binding fibroblast growth factors (FGF). Differentiation of osteoblasts to mature cells may be mediated by IGF-I and bone morphogenetic protein 2 (BMP-2). Factors that may bring about cessation of osteoblastic activity include TGFβ. Thus TGFβ is pivotal to bone formation and may be released as a consequence of bone resorption; there most likely being a cascade of growth factors mediating cellular activities and events. The above mediators are not only secreted by cells intimately involved in bone resorption, but are also secreted by osteoblasts.

Of the overall control of bone remodelling at the cellular level we have only scratched the surface. We do not know the nature of the signals produced by osteocytes or by bone lining cells that transmit the requirement for increased resorption to osteoblastic cells in the appropriate area. Are there different osteoblast phenotypes that are responsible for osteoclastic induction, stimulation and inhibition? How do the cells know when resorption is sufficient, and whether subsequent bone formation should occur?

OVERVIEW OF MEMBRANE-DERIVED LIPID MEDIATORS

The eicosanoids are members of a group of substances comprising prostaglandins and leukotrienes which are released by a host of mechanical, thermal, bacterial and other insults and contribute importantly to the signs and genesis of inflammation as well as playing important roles in bone remodelling (Table 1; for a review see Collett and Stewart, 1991).

The existence of biologically active lipids was first recognised during the 1930s with the discovery of prostaglandins and the identification of a slow-reacting substance released during treatment of isolated lung tissue with snake venom or with an antigen. The latter activity is now known to be a mixture of cysteinyl leukotrienes which may contribute to the pathogenesis of asthma and other airway diseases (Piper and Samhoun, 1987). The discovery that non-steroidal anti-inflammatory drugs (NSAIDS) inhibited the production of prostaglandins by Vane in 1971 provided the impetus for an intensive period of investigation of the role of eicosanoids in (patho)physiological processes. The consequent development of compounds that interfere selectively with the formation or actions of certain eicosanoids heralds novel therapeutic approaches to the management of inflammatory and thrombotic disorders.

TABLE 1. FACTORS IMPLICATED IN BONE REMODELLING

Mediator	Former Name	Effect
Prostaglandins		
PGE_1		Bone resorption
PGE_2		Bone resorption inhibits osteoblasts
PGI_2		Bone formation inhibits osteoclasts
Leukotrienes		
LTB_4		Bone resorption inhibits osteoblast proliferation
Interleukins		
IL-1α, IL-1β	Osteoclast activating factor Lymphocyte activating factor Mononuclear cell factor	Bone resorption
IL-2	T cell growth factor	Bone resorption
IL-6	B-cell growth factor-II B-cell stimulatory factor-2 Interferon b2 Hepatocyte stimulating factor	Bone resorption
IL-11		Bone resorption
Tumour Necrosis Factors (TNF)		
TNF	TNF-α, Cachectin	Stimulates osteoclastic bone resorption
Lymphotoxin	TNF-β	Stimulates osteoclastic bone resorption
Interferons		
IFN-γ	immune interferon	Inhibits osteoclastic bone resorption
Colony-Stimulating Factors (CSF)		
Macrophage-CSF (M-CSF)	CSF-1	Osteoclast formation

Growth Factors		
Fibroblast growth factors (FGF)		Osteoblast proliferation
Insulin-like growth factor-I (IGF-I)	Somatomedin C	Osteoblast proliferation Osteoblast differentiation
Insulin-like growth factor-II (IGF-II)	Somatomedin A	Osteoblast proliferation
Platelet-derived growth factor (PDGF)		Osteoblast chemotaxis Osteoblast proliferation
Transforming growth factor-β (TGF-β)	Bone derived growth factor	Osteoblast chemotaxis Osteoblast proliferation
Bone morphogenetic protein 2 (BMP-2)		Osteoblast differentiation
Bone morphogenetic protein 3 (BMP-3)	Osteogenin	Inhibits osteoclastic bone resorption
Hormones		
Parathyroid hormone (PTH)		Calcium homeostasis Stimulates osteoclasts
Calcitonin		Inhibits bone resorption

The phospholipid membrane contains precursors for a number of biologically active lipid mediators. The dominant precursor is arachidonic acid which is transformed into a class of lipid mediators known as eicosanoids. Arachidonic acid is esterified in a range of phospholipids and is hydrolysed enzymatically by an enzyme called phospholipase A_2 (PLA_2) (Figure 1). Only this "free" or non-esterified arachidonic acid is available to two major enzyme systems, cyclo-oxygenase or lipoxygenase. The metabolism of membrane phospholipids by PLA_2 represents the rate limiting step in the formation of eicosanoids under normal conditions. Arachidonic acid is derived from the diet and its abundance in lipid membranes reflects dietary intake and the presence of other fatty acids that may compete for esterification in lipid membranes.

Over the last two decades it has been established that a subclass of phospholipids containing ether-linked alkyl chains give rise not only to arachidonic acid, but also to the immediate precursor of platelet-activating factor (Paf) (Braquet *et al.*, 1987). Paf may be produced simultaneously with the eicosanoids in certain cell types (notably those with a role in inflammation).

Cyclo-oxygenase is an enzyme present in almost all cells and since it is constitutively active, the subsequent formation of prostaglandins is limited only by the availability of non-esterified arachidonic acid (Figure 1). The products of cyclo-oxygenase, the cyclic endoperoxides, may be converted both enzymatically and non-enzymatically to the stable prostaglandins (PGE_2, $PGF_{2\alpha}$ or PGD_2), to an unstable but potent anti-platelet substance, prostacyclin (PGI_2), or to an even more

unstable platelet activator, thromboxane A_2. The profile and amount of these cyclo-oxygenase products varies according to the cell type and its level of activation.

Leukotrienes are a group of substances derived from arachidonic acid by means of the enzyme 5-lipoxygenase (Brain and Williams, 1990; Piper and Samhoun, 1987).

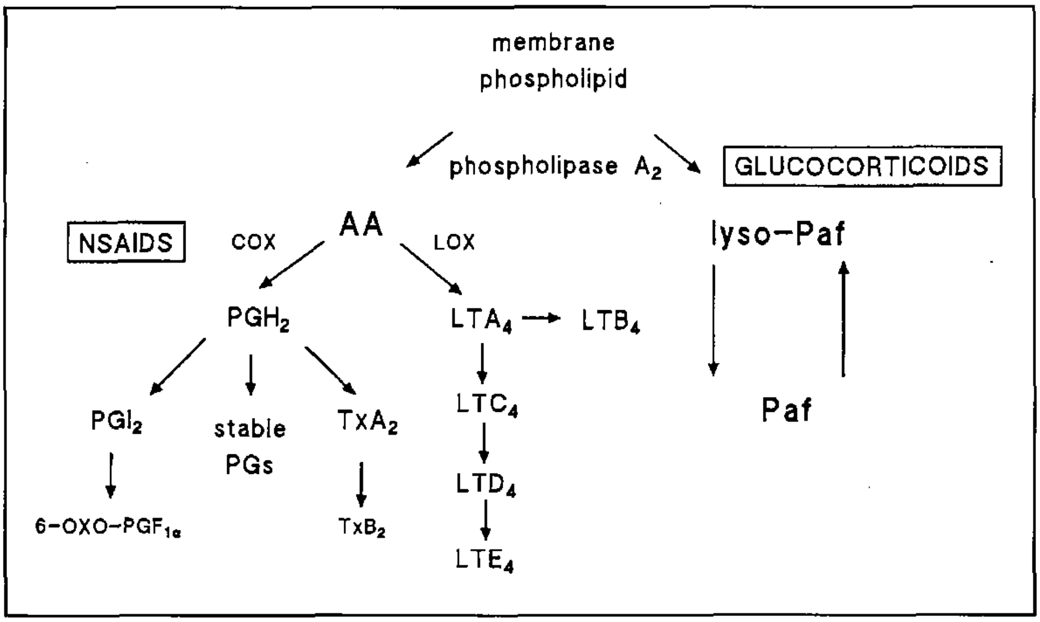

Fig. 1. The metabolism of membrane phospholipids by phospholipase A2 is regulated by anti-inflammatory glucocorticoids resulting in reductions in the release of arachidonic acid (AA) and lyso-platelet-activating factor (lyso-Paf) from the membrane. Free arachidonic acid is available to cyclo-oxygenase for prostaglandin (PG) and thromboxane (Tx) synthesis which is inhibited by non-steroidal anti-inflammatory drugs (NSAIDS). In inflammatory cell types, arachidonic acid may also be transformed into leukotrienes (LTs) by lipoxygenase. The biological properties of these membrane-derived phospholipids are reviewed in the text. *Reprinted with kind permission of Australian Orthodontic Journal; Collett, A.R. and Stewart, A.G. (1991) Eicosanoids: physiology update and orthodontic implications. Aust. Orthod. J., 12:116-123.*

The 5-lipoxygenase enzyme has a more restricted distribution being found in epithelial cells, monocytes/macrophages, polymorphonuclear leukocytes and certain neurones (Brain and Williams, 1990). Furthermore, lipoxygenase requires specific activation in addition to the availability of non-esterified arachidonic acid to produce leukotrienes. Interest in a possible role of leukotrienes in orthodontic tooth movement derives from the finding that bone organ cultures possess an active 5-lipoxygenase enzyme system, which is capable of leukotriene production (Offenbacher *et al.*, 1986). The leukotrienes fall into two classes which are distinguished by differences in both their chemical and biological properties (Piper and Samhoun, 1987): the cysteinyl-containing leukotrienes, LTC_4, LTD_4 and LTE_4 which are potent constrictors of smooth muscle; the dihydroxy acid, LTB_4 which is a leukocyte chemoattractant.

Biological Effects of Membrane-Derived Mediators

In general, mediators derived from membrane phospholipids are either chemically (prostacyclin, thromboxane A_2) or enzymatically (Paf, prostaglandins) unstable and therefore exert effects close to their site of formation when produced in physiological amounts. They have actions at very low concentrations (10^{-15} to 10^{-8} M) via the activation of specific and separate membrane receptors which are linked to a variety of intracellular signalling mechanisms.

Prostaglandin E_2 is one of the stable prostaglandins, since it survives long enough to circulate if generated in sufficient quantity. However, the pulmonary vascular endothelial cells takeup and inactivate PGE_2 thereby restricting its systemic role.

Prostacyclin (PGI_2) is produced by macrophages and smooth muscle cells as well as being the major eicosanoid released from vascular endothelial cells, where it is considered to exert localised inhibitory effects on platelet activation and vascular smooth muscle tone.

Lipoxygenase Products: Cysteinyl leukotrienes

Activation of 5-lipoxygenase in macrophages, eosinophils and mast cells results in the generation of leukotriene A_4 (LTA_4) which is further transformed to LTC_4 by the enzyme glutathione S-transferase. LTC_4 is converted to LTD_4 and then to LTE_4. These products, originally known as SRS-A (slow reacting substance of anaphylaxis), are now collectively called cysteinyl leukotrienes. Each product has similar actions at nanomolar concentrations which include: vasoconstriction in pulmonary, coronary and cerebral vascular beds; vasodilatation in the femoral circulation; increased vascular permeability; bronchoconstriction; decreased myocardial contractility (see Piper and Samhoun, 1987, for a review).

Leukotriene B_4

Some cell types (neutrophils, epithelial cells) have 5-lipoxygenase activity, but lack glutathione S-transferase and therefore do not produce cysteinyl leukotrienes. In these cells, leukotriene B_4 is the sole leukotriene derived from LTA_4 by the action of LTA_4 hydrolase. LTB_4 is a highly potent chemotactic agent inducing the accumulation of inflammatory cells (predominantly neutrophils) at the focus of inflammation (Brain and Williams, 1990).

Platelet-Activating Factor

Platelet-activating factor (Paf) is an extremely potent pro-inflammatory mediator generated from a subclass of membrane phospholipids following activation of PLA_2 (Hanahan, 1986; Braquet *et al.*, 1987). Consequently, Paf synthesis often accompanies eicosanoid generation in inflammatory cells. In addition to a common initial pathway for Paf and eicosanoids, these products have a remarkably similar spectrum of action. Paf is a potent chemoattractant and activator of leukocytes. Although the name Paf clearly indicates a stimulatory effect on platelets, more recent studies have established a much wider distribution of receptors and a range of effects including pulmonary and coronary vasoconstriction, impairment of cardiac contractility and ulceration of the gastric mucosa.

Originally, Paf was considered to be produced only by inflammatory cells (macrophages, eosinophils and neutrophils). It is now recognised that this inflammatory mediator is produced and retained by vascular smooth muscle and endothelial cells, neurones and fibroblasts. The function (physiological) of Paf in these cell types is yet to be elucidated, but one possibility is a role in transmembrane signalling (Bratton and Henson, 1989; Stewart *et al.*, 1990). It is

conceivable Paf may play a role in various (patho)physiological processes, such as bone remodelling.

HORMONES

Parathyroid hormone (PTH) acts on both bone resorbing and forming cells. PTH appears to indirectly stimulate osteoclasts with the mediators including PGE, IL-6 and TGFβ. When PTH is continuously present around bone cells the net effect is resorption. In contrast, low intermittent doses result in bone formation. PTH is the prime regulator of calcium homeostasis.

The hormone calcitonin is secreted by the thyroid gland and may play a role as an acute regulator of calcium homeostasis. The hormone acts directly on osteoclasts to inhibit bone resorption.

1,25 Dihydroxyvitamin D_3 is produced by the proximal tubules of the kidney. Vitamin D deficiency results in deficient mineralisation of bone resulting in rickets in children and osteomalacia in adults. It appears the effect on bone mineralisation relates to an indirect effect in providing the required calcium and phosphate. Excess Vitamin D leads to an increased rate of bone resorption (Mundy, 1995). The effects of 1,25 dihydroxyvitamin D_3 on osteoclastic bone resorption may be synergistic with PTH.

LOCAL REGULATORS

Calcitonin Gene-Related Peptide and Substance P

An increase in nerve fibres expressing calcitonin gene-related peptide and substance P in the periodontal ligament, pulp and gingival mucosa has been found following orthodontic tooth movement in experimental animals (Norevall *et al.*, 1995; Kvinnsland and Kvinnsland, 1990; Nicolay *et al.*, 1990; Saito *et al.*, 1991).

Cytokines

If one accepts the pressure-tension hypothesis as outlined above, the obvious question to address is can cells distinguish between tension and compression, and if so, how? Evidence suggests bone cells do not distinguish between tension and compression (Meikle *et al.*, 1989). It is suggested that cytokines might be the mediators of mechanically-induced bone remodelling (Table 1). Cytokines are small proteins produced by cells which modify the behaviour of other cells. Various workers have proposed models for explaining bone remodelling and it is postulated that immune cells, such as lymphocytes and monocytes, and stromal fibroblasts near active bone forming and bone resorbing surfaces might modulate the functions of osteoblasts, osteoclasts and their progenitor cells during physiological and pathological bone remodelling. The effector cells may act through either direct contact, or by means of release of soluble ligands or cytokines. These cytokines include substances such as interleukin-1 (IL-1) or tumour necrosis factor, lymphotoxins and transforming growth factors. The mechanisms and effects of cytokines are, in general, poorly understood. This is not helped by the complexity of their actions, and the fact that their effects exhibit marked variation. For example, transforming growth factor ß (TGF-ß) promotes some processes, and inhibits others. Thus the name TGF is only accurate in certain cases. A cytokine that is thought to be prominent is interleukin-1 (lymphocyte activating factor). IL-1 is one of the bone resorbing factors which have previously been denoted as osteoclast-activating factor (OAF), a term that is now redundant. In the human, at least two distinct gene products have been cloned and termed IL-1α and IL-1β, and these two forms have

been found in every animal species studied to date. Interleukin- 1 has been shown to enhance various immune responses, including B lymphocyte differentiation, antibody secretion, and T lymphocyte proliferation. IL-1 has also been shown to mediate a number of non-immunological events such as protein synthesis, endogenous-pyrogen induced fever, fibroblast proliferation, bone resorption, and collagenase and prostaglandin production by fibroblasts and chondrocytes (Billingham, 1987; Meikle *et al.* 1989). IL-1 is a potent stimulator of bone resorption, involving stimulation of prostaglandins, and it appears its activity is modulated by calcitonin and by the lymphocyte product interferon-g (Gowen and Mundy, 1986). Also, in experimental studies the application of tensile stress to periosteal fibroblasts resulted in the production of an interleukin-1 inhibitor (Meikle *et al.*, 1989), again, evidence for a role for interleukin-1 in bone remodelling.

Although cytokine receptor-mediated synthesis of eicosanoids, such as prostaglandin E_2 (PGE_2) has been documented (Krane *et al.*, 1988), the actual interdependency of cytokine activity and prostaglandin production is still controversial. It may be that IL-1 stimulated bone resorption is not dependent on cyclo-oxygenase derived derivatives of arachidonic acid (Amano *et al.*, 1988), but agents such as prostaglandins enhance the effect of IL-1, or in fact, IL-1 and prostaglandins behave in a synergistic manner (Dewhirst *et al.*, 1987a). It is also possible IL-1b acts to enhance the production of PGE, based on observations of periodontal ligament cells subject to mechanical stress (Saito *et al.*, 1991), with delivery of mechanical stress alone not significantly increasing PGE production. Increases in both PGE and IL-1b in the gingival crevicular fluid of orthodontic patients has been detected (Grieve *et al.*, 1994). That the IL-b levels increased rapidly with PGE levels peaking later supports the view that IL-b stimulates PGE production. The effect of IL-1 on PGE_2 production is most likely mediated by induction of cyclo-oxygenase synthesis (Raz *et al.*, 1988).

At present, interleukins would seem to play an important role in bone remodelling, however, their actions require further elucidation.

In support of a mediating role for cAMP are findings (Dewhirst *et al.*, 1987b, 1990) where substances such as parathyroid hormone, forskolin, and IBMX, which elevate cAMP levels, display synergism with IL-1. Thus, activation of the cAMP pathway in bone cells would appear to be a sufficient signal for an agent to interact synergistically with IL-1. There are various possible interactions between cytokine stimulation and prostaglandin production (Krane *et al.*, 1988). PGE_2 released by cytokine-stimulated cells binds to specific PGE_2 receptors on the surface of the target cells or that of neighbouring cells to initiate another (besides cytokine-initiated) series of signal transduction events. These signals produced by a second mediator such as prostaglandins may either operate in the same direction, or in the opposite direction as signals induced by cytokines. Thus, the effects of IL-1 are not only transduced by specific signals following binding to receptors, but are also subject to modulation resulting from the simultaneous stimulation of synthesis of PGE_2, which in turn acts on its own receptors to induce different signals. Furthermore, cytokines may modify responses to the second mediators. There do appear to be site-dependent discrepancies in the effects on bone resorption. For example, calcium

release stimulated by IL-1 appears to be inhibited by indomethacin in foetal mouse forearm bones but not in neonatal mouse calvaria (Gowen and Mundy, 1986; Sato *et al.*, 1986). Is there perhaps a difference between tissues of mesodermal and ectomesenchymal origin in their responses to biochemical mediators?

IL-2 appears to be implicated in the attraction and/or proliferation of osteoclast progenitors as well as the stimulation of acid production by osteoclasts (Davidovitch, 1991).

Interest has also surrounded a possible part for IL-6 in the stimulation of bone resorption. IL-6 is a pleiotropic cytokine with some similarities to IL-1. Its behaviour is reflected in its previous names of hepatocyte stimulating factor, B cell growth factor 2, hybridoma and plasmacytoma growth factor, and interferon-β_2. IL-1 has been reported to stimulate the release of IL-6 from human osteoblasts (Littlewood *et al.*, 1990). Recent evidence suggests that unlike IL-1, IL-6 does not stimulate bone resorption (Al-Humidan *et al.*, 1991), but does, however, inhibit resorption stimulated by parathyroid hormone. It is conceivable that IL-6 may act as a locally produced inhibitor and therefore regulator of bone resorption induced by osseotropic hormones. IL-6 may be exerting its actions on systems other than those involving cAMP. Although, as stated above, parathyroid hormone does cause cAMP levels to increase, evidence also suggests (Lerner *et al.*, 1991) that parathyroid hormone stimulation of bone resorption is not solely mediated by cAMP.

A relatively recently discovered cytokine is IL-11 (Martin and Ng, 1994). It is a product of bone marrow stromal cells and appears to stimulate osteoclast formation and bone resorption. The effect on osteoclast formation may also be prostaglandin mediated.

Interferon-γ is a potent inhibitor of bone resorption (Gowen and Mundy, 1986). Gowen *et al.*, (1986) reported that mouse interferon-γ preferentially inhibited bone resorption induced by cytokines, such as IL-1 and some tumour necrosis factors (TNF-α and TNF-β), but did not efficiently inhibit bone resorption induced by systemic, calcium-regulating hormones, such as parathyroid hormone and 1,25-dihydroxyvitamin D_3.

The mechanism by which interferon-γ inhibits bone resorption is controversial. Interferon-γ has been suggested to inhibit IL-1 by means of a PGE_2 pathway (Browning and Ribolini, 1987; Hoffman *et al.*, 1987), and by a PGE_2-independent mechanism (Fujii *et al.*, 1990; Lerner *et al.*, 1991).

With regard to the effects of TGF-β on bone formation, this cytokine has been reported to stimulate bone resorption in cultured mouse calvaria by means of a PGE_2 mediated mechanism (Tashjian *et al.*, 1985). TGF-β has been ascribed a role in stimulating appositional formation of woven bone that is later remodelled into lamellar bone, this effect not being prostaglandin dependent (Mackie and Trechsel, 1990). In addition, TGF-β did not appear to directly influence bone resorption.

Tumour necrosis factor and lymphotoxin are cytokines that have been implicated in the stimulation of osteoclastic bone resorption (Mundy, 1995). Their effects are in part mediated by prostaglandins. They appear to have dual actions in being able to both stimulate the formation of new osteoclasts and activate mature osteoclasts.

Prostaglandins

Various workers have proposed models for explaining tooth movement in terms of biochemical mediators. Tooth movement may involve two pathways. The first pathway is the physiological response associated with normal bone growth and remodelling while second pathway involves a tissue inflammatory response as a result of an orthodontically applied force. Various secondary messengers such as cyclic adenosine 3',5'-cyclic phosphate (cAMP), a number of humoral factors such as prostaglandins (PG) and cytokines, and various neurotransmitters such as substance P and vasoactive intestinal peptide participate in the process. (Davidovitch *et al.*, 1988, 1989; Mostafa *et al.*, 1983)

Interest recently has focussed on a role for eicosanoids in tooth movement. Prostaglandins of the E and F and prostacyclin (PGI_2) series have long been associated with bone remodelling. Prostaglandins have been observed to stimulate new bone formation *in vivo*, to stimulate resorption in bone organ culture, and to inhibit isolated osteoclast function (Arnett, 1990; Fuller and Chambers, 1989). However, there is no contradiction between the stimulatory effect of prostaglandins on bone formation and on bone resorption, since the two processes are carried out by separate groups of cells, each of which seem to be raised to higher levels of activity (Rodan *et al.*, 1989).

A dual effect of prostaglandins on bone resorption and bone formation would be consistent with the increased bone turnover resulting from mechanical stimulation. PGE_2 and PGI_2 are thought to be locally produced modulators of bone resorption and possibly bone formation (Binderman *et al.*, 1989; Sandy and Harris, 1984; Somjen *et al.*, 1980; Yamasaki *et al.*, 1980; Yeh and Rodan, 1984), the resorptive effects perhaps being mediated by osteoclastic cAMP. There may exist a subpopulation of bone cells that produce prostaglandins as local regulators of bone remodelling. Of interest is that while osteoclasts seem 100 times more sensitive to inhibition by PGI_2 than PGE_2, the reverse is true for osteoblasts (Chambers, 1991) and thus resorption may be enhanced by suppressed osteoblastic activity. Therefore, a cell such as an osteocyte, by producing PGE_2 in response to mechanical or morphogenetic information, could direct remodelling to favour resorption, with the concentration being too low for osteoclastic inhibition. Intracellular calcium appears to be a prerequisite for prostaglandin mediated bone resorption (Yamasaki, 1989).

Also supporting a role for prostaglandins in bone resorption accompanying orthodontic tooth movement is the finding in which a significant decrease in osteoclasts in bone adjacent to an orthodontically moved tooth was observed in rabbits treated with the cyclo-oxygenase inhibitor flurbiprofen, compared to control rabbits (Sandy and Harris, 1984). However, this was not associated with a change in tooth movement, suggesting a role for other mediators as well. Similar findings relating to cyclo-oxygenase inhibitors have been reported by others (Wong *et al.*, 1992; Saffar and Leroux, 1988). A problem with studies such as these is the inability to determine the degree of cyclo-oxygenase inhibition at the cellular level *in vivo* and to thus be sure that the inhibition exceeds a threshold to be able to detect an effect. In contrast, indomethacin has been reported to inhibit tooth movement in rats (Mohammed *et al.*, 1989). Also, human periodontal ligament fibroblasts have been found to synthesise PGE in response to the application of mechanical stress and IL-1β, and this

response was blocked by addition of indomethacin to the incubation media (Saito *et al.*, 1991). In addition, animal studies in pigs have found indomethacin to reduce bone turnover adjacent to teeth subject to orthodontic forces (Giunta *et al.*, 1995). The extent of bone surfaces involved in resorption was significantly reduced.

Part of the prostaglandin increase (at least PGE_2 and PGI_2) occurring in response to mechanical stimulation may be mediated by bradykinin, a substance formed during the vascular part of the inflammatory reaction (Ljunggren *et al.*, 1991). This action of bradykinin appears to be mediated by bradykinin receptors on osteoclasts coupled to enhanced prostaglandin synthesis.

PGE_1 administered locally and systemically to rats in which a molar was moved orthodontically with an orthodontic elastic band revealed histological findings of an increased level of bone resorption in the PGE_1 treated rats compared to control rats (Lee, 1990). Subsequently, tooth movement in rats was shown to increase following administration of PGE_1 (Yamasaki *et al.*, 1984) and PGE_2 (Leiker *et al.*, 1995). Of particular interest is the finding that tooth movement was not further enhanced by increasing the dosage of PGE_2, nor by repeated injections on a weekly basis. PGE_2 administration did give rise to increased root resorption and this feature was related to the concentration and frequency of administration. However, the overall picture of PGE_2 mediated root resorption is unclear with reports of no significant resorption (Brudvik and Rygh, 1991) or inconsistent results; with short term PGE_2 giving rise to root resorption in rats while longer use did not produce the same effect (Boekenoogen *et al.*, 1996).

PGE_1 has been administered submucosally to a limited number of patients undergoing orthodontic treatment and the teeth having had submucosal PGE_1 administration showed a significantly greater rate of movement than control teeth in the same patient (Yamasaki, 1989). This suggests prostaglandins could be useful agents to administer in order to shorten treatment time and also aid in selective tooth movements. In addition, anchorage may be enhanced by the administration of cyclo-oxygenase inhibitors.

However, the practical aspects of treatment involving administration of prostaglandins have yet to be evaluated. Even though the rate of tooth movement following prostaglandin administration appears to be increased, it may well be that a longer period of retention is required for these teeth; that is, no overall change in treatment time. Also, a major factor is the willingness of patients to submit themselves to repeated elective submucosal injections for what may turn out to be only a short decrease in treatment time.

With regard to the use of simple analgesics during active treatment, available evidence, based on observations of orthodontic tooth movement, would suggest paracetamol to be the agent of choice at this time (Kehoe *et al.*, 1996).

Leukotrienes

Some evidence implicating leukotrienes in bone remodelling comes from findings that the administration of the 5-lipoxygenase inhibitor, piriprost, to rats enhances mechanically-induced bone formation (Collins et al., 1987a & b). However, results regarding the actions of piriprost must be evaluated with caution as this compound also has effects on a number of other enzyme systems, such as, for example cytosolic glutathione transferase. AA861 is a more selective 5-lipoxygenase inhibitor and administration to rats having had orthodontic mesial tipping appliances

fitted to the maxillary first molars caused a decrease in orthodontic tooth movement (Mohammed *et al.*, 1989). The administration of AA861 was associated with a reduction in LTB_4 in tissue adjacent to maxillary first molars. Experimental studies (Meghji *et al.*, 1988; Ren and Dziak, 1991) examining the effects of leukotrienes on osteoblastic cell proliferation give further support to a local modulatory role in bone remodelling.

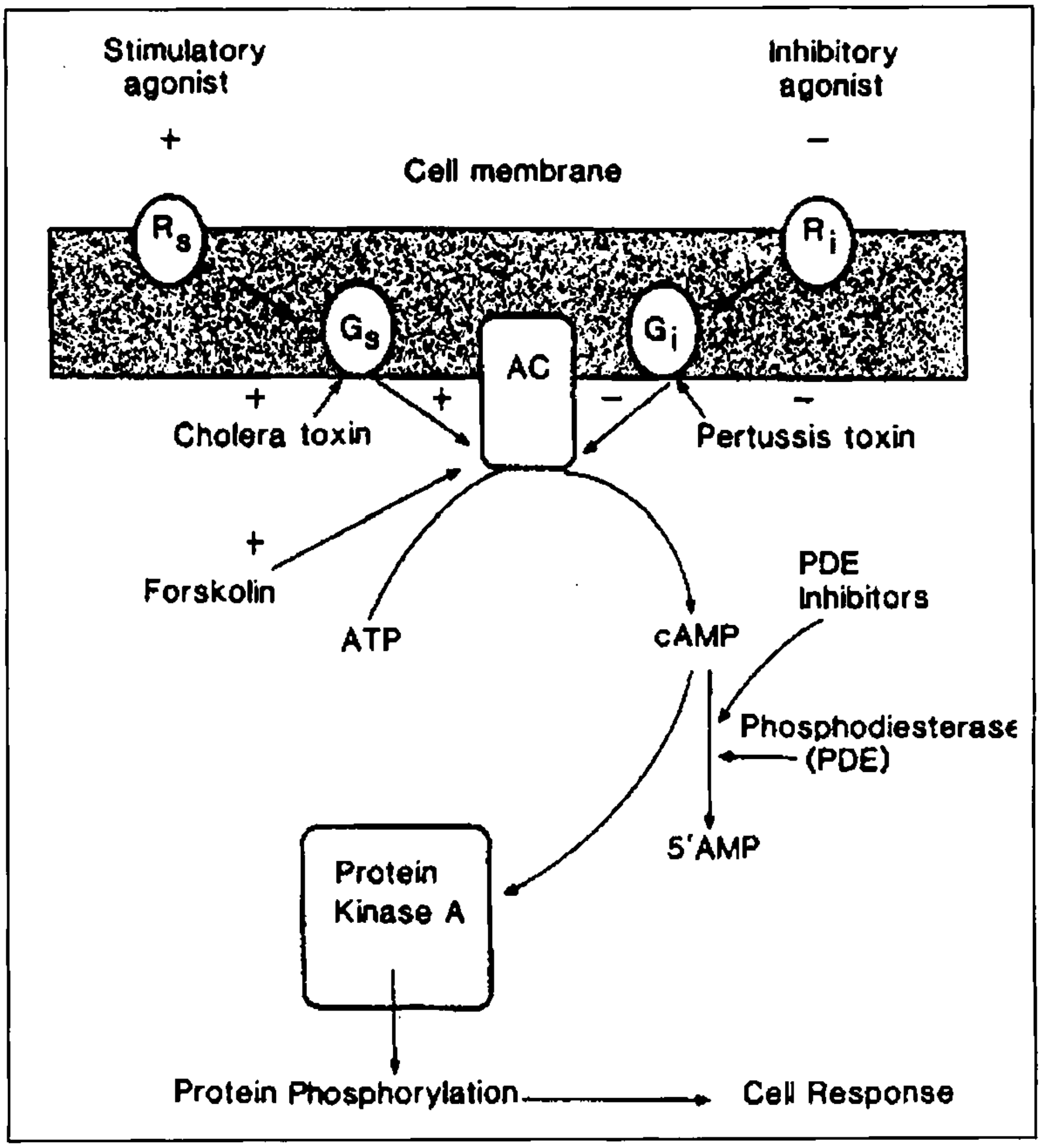

Fig. 2. Cellular events that regulate cAMP production. Stimulatory (Rs) and inhibitory (Ri) receptors regulate production, interacting with their respective G proteins to control adenylate cyclase (AC) production. Adenylate cyclase results in formation of cAMP from ATP, with cAMP activating protein kinase A, an enzyme involved in protein phosphorylation. *Reprinted with kind permission of European Journal of Orthodontics; Sandy J.R. and Farndale, R.W. (1991) Second messengers: regulators of mechanically-induced tissue remodelling. Eur. J. Orthod., 13:271-278.*

SECOND MESSENGERS

The first stage in the cellular response is the binding of a cell membrane receptor by an agonist which is followed by interaction with a G protein. G proteins are membrane bound transducing proteins which bind guanine nucleotides such as guanosine triphosphate (GTP) or guanosine diphosphate (GDP). The G proteins of significance here are Gs (stimulatory regulator of adenylate cyclase), Gi (inhibitory regulator of adenylate cyclase) and Gp (the putative stimulatory regulator of the phosphtidylinositol signalling pathway), as shown in Figures 2 and 3. Ligand interaction with a stimulatory receptor (Rs) result in a conformational change to the receptor environment with subsequent activation of Gs. In a similar manner, Gi is linked to an inhibitory receptor (Ri). The Gp protein is postulated to be linked to a receptor which when bound by a ligand activates Gp and subsequently the (phosphtidylinositol) PI pathway (For reviews see Sandy and Farndale, 1991; Sandy *et al.*, 1993).

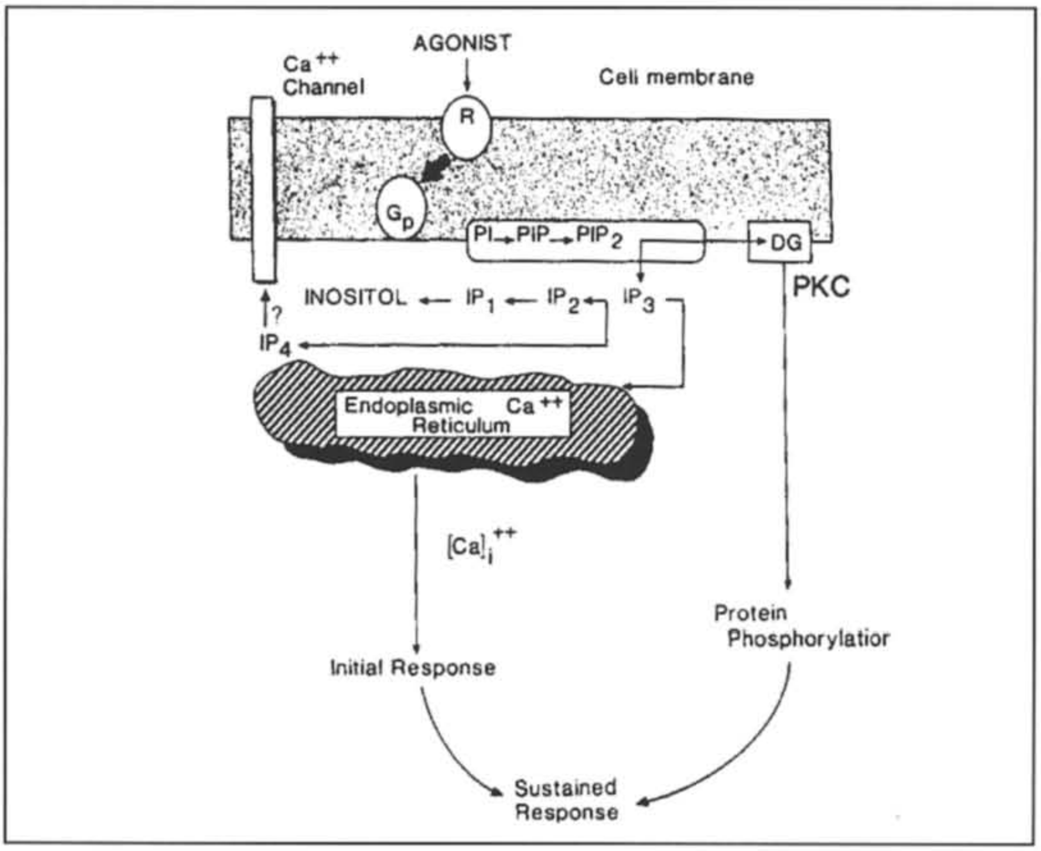

Fig. 3. Membrane events involved in the production of inositol phosphates. In a similar manner to cAMP production, an agonist binds a receptor intimately associated with a G protein. Phosphatidylinositol biphosphate (PIP_2) is cleaved into diacylglycerol (DG) and inositol triphosphate (IP_3) by the action of phosphodiesterase. IP_3 mobilises intracellular calcium (Ca^{++}) with IP_3 being either recycled, or phosphorylated to tetrakisphosphate (IP_4), which in turn, may be involved in gating calcium through the membrane. DG remains within the membrane and is able to continue to activate protein kinase C (PKC). The second messenger pathways allow for early and sustained responses. *Reprinted with kind permission of European Journal of Orthodontics; Sandy J.R. and Farndale R.W. (1991) Second messengers: regulators of mechanically-induced tissue remodelling. Eur. J. Orthod., 13:271-278.*

The cAMP pathway (Figure 2) is under the control of the Gs and Gi proteins. The enzyme, adenylate cyclase, is in turn activated or inhibited as a result of receptor ligand binding. Activation results in the generation of cAMP from ATP. cAMP in turn activates protein kinase A, an enzyme that phosphorylates cellular proteins giving rise to a number of cellular responses.

The association between PGE as a first messenger and cAMP as a second messenger is supported by considerable experimental evidence (Binderman *et al.*, 1988, 1989; Davidovitch *et al.*, 1989; Mundy and Roodman, 1987; Ngan *et al.*, 1988). The cAMP pathway with the involvement of PGE is widely accepted as being essential to bone remodelling in response to orthodontically applied forces to teeth. However, this pathway is most probably not the only system involved.

The phosphoinositide (PI) pathway is depicted in Figure 3, and the important step in the pathway is the cleavage of phosphatidylinositol biphosphate (PIP_2) into two second messengers; diacylglycerol and inositol triphosphate (IP_3) by a phosphodiesterase. IP_3 mobilises intracellular calcium from the endoplasmic reticulum and is a mediator of mitogenesis. IP_3 is either dephosphorylated to free inositol which is recycled into the PI pathway or phosphorylated to IP_4 (tetrakisphosphate). IP_4 together with IP_3 may have a role in gating Ca^{2+} through calcium channels. Diacylgylcerol activates protein kinase C which in turn phosphorylates other cellular proteins resulting in a sustained response (Sandy and Farndale, 1991; Sandy *et al.*, 1993).

The PI pathway thus may be involved in changes seen in mechanically deformed tissues. It seems likely that the PI pathway operates in conjunction with the cAMP second messenger system to mediate orthodontically induced bone remodelling.

THE CYTOSKELETAL MATRIX

The three main components of the cytoskeleton are microtubules, microfilaments and intermediate filaments (Sandy *et al.*, 1993). Actin is the major protein subunit of microfilaments. Other associated proteins include myosin, vinculin and talin. Microfilaments form junctional complexes with the extracellular matrix at the cell membrane known as focal contacts, adhesion plaques or focal adhesions. Many of the extracellular proteins contain a common peptide sequence which are recognised by membrane proteins known as integrins. Integrin binds to fibronectin in the extracellular matrix and to talin intracellularly. Actin and vinculin bind to this complex and thus the interaction provides a link between the cytoskeleton and extracellular matrix (Figure 4).

THE BONE MATRIX

It has been postulated (Lanyon, 1987) that the explanation for the adaptation of bone to functional loading lies with the osteocytes. The osteocytes would sense the distribution, rate of change and strain magnitude in the bone matrix and communicate with bone surface cells that are responsible for the remodelling. The more important aspect here is postulated to be an abnormally distributed strain rather than the magnitude of the strain. In addition, rather than osteocytes only being able to detect "real time" strain, the bone matrix, by means of its proteoglycans, is able to "capture" the strain. Thus very transient applied strains are able to generate long-lived changes in bone.

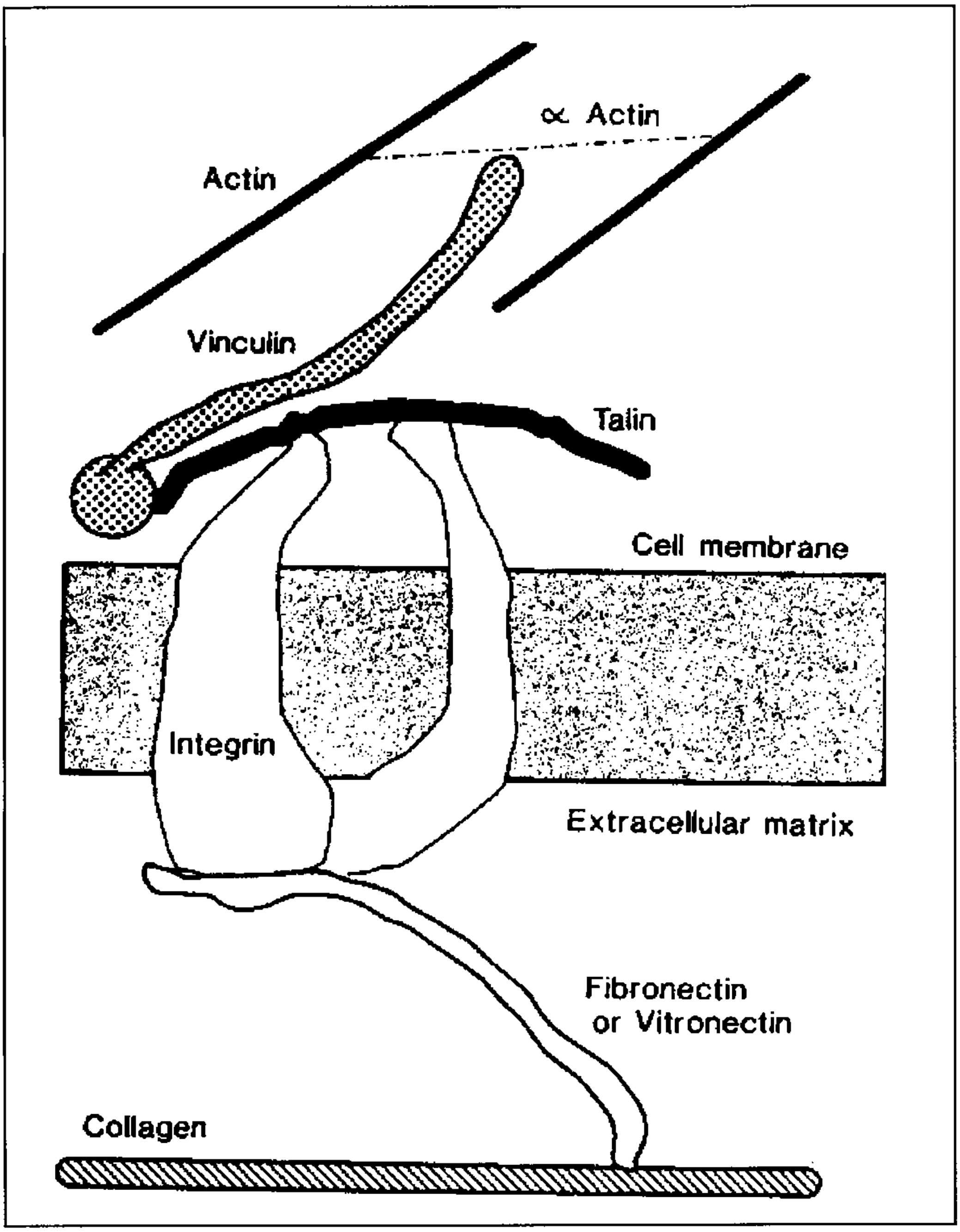

Figure 4. Diagrammatic representation of interactions of molecules at focal contacts. The cytoskeleton is linked through the membrane protein, integrin, to the extracellular matrix. Integrin's interaction with microfilaments is by means of associated proteins; talin on the intracellular side and fibronectin or vitronectin in the extracellular matrix. *Reprinted with kind permission of American Journal of Orthodontics and Dentofacial Orthopedics; Sandy J.R., Farndale R.W. and Meikle,M.C. (1993). Recent advances in understanding mechanically induced bone remodeling and their relevance to orthodontic theory and practice. Am. J. Orthod. Dentofac. Orthop., 103:212-222.*

MECHANOSENSITIVE ION CHANNELS

Cells possess membrane ion channels and this could provide a mechanism for the cell regulating its biochemical cellular activity in response to applied strains and stresses. It has been proposed that mechanosensitive ion channels (Morris, 1990) are either closed or open depending on the stress at the membrane. The role of such channels has yet to be elucidated.

ENDOGENOUS ELECTRIC SIGNALS

Many electrical theories have been proposed to account for the mechanism involved in the translation of a force on bone into resorption or formation. Two types of electrical signals have been described that arise in bone endogenously (Norton, 1989). The stress-generated potential is the best known of these, and is the voltage generated when the bone is subjected to mechanical stress. The origin of these potentials is apparently the organic component of bone. The second type of endogenous electrical signal that arises in bone is the steady state or that which is called the bioelectric potential (Friedenberg and Brighton, 1966; Norton, 1989). Active areas of bone, such as sites of active growth or repair, result in bioelectric potentials that are relatively negative. In quiescent areas the potentials are neutral. The physiological significance of these bioelectric potentials is as yet unknown, but it may be linked with cell migration, proliferation, and/or differentiation.

The stress-generated potentials are of particular interest in relation to elucidating mechanisms of orthodontic tooth movement. One such stress-generated potential is referred to as piezoelectricity, broadly defined as electricity resulting from pressure on crystals (Bassett, 1968). The source of piezoelecticity is most likely the collagen component (Marino *et al.*, 1970; Marino and Becker, 1975) and this phenomenon has been previously implicated in bone remodelling, including that in response to orthodontic loading (Bassett and Becker, 1962; Shamos *et al.*, 1963; Zengo *et al.*, 1973, 1974). However, the effects of streaming potentials (below) were not considered.

In fact, contemporary thought is stress-generated piezoelectric currents probably have little to do with bone remodelling *in vivo* (Anderson and Eriksson, 1968; Chakkalakal and Johnson, 1981; Norton, 1989; Spadaro, 1991). Evidence suggests the streaming potential mechanism to be the functional stress related potential in moist and living bone with the piezoelectricity primarily responsible for the stress related potential seen in dry bone. Streaming potentials result from the adsorption of one type of ion onto the surface of a molecule which has an associated diffuse layer of ions of opposite polarity extending out from the surface of the molecule. When ionic fluid streams past the molecule as a result of an applied stress, there is a net transport of one type of ion, with a resulting potential gradient. The stress-generated streaming potentials may account for the fine tuning of remodelling and may play a role in transducing mechanical stimuli into a biological responses during the adaptive remodelling and maintenance of bone (Norton, 1989; Spadaro, 1991).

Applied Electric Signals

Orthodontists have attempted to use electric perturbations to move teeth more efficiently. One approach has been to apply direct current to the gingiva directly over the bone on the compression side of the tooth movement (Davidovitch *et al.*, 1980a,b,c,d), which apparently induced an increase in bone remodelling, a concomitant tooth movement, and alteration of periodontal tissue

nucleotide levels for the 2 week duration of the experiment. Pulsated mechanical forces have been used (Shapiro *et al.*, 1975; Stark and Sinclair, 1987) in order to increase the rate of tooth movement, however, results have not been consistent (Beeson *et al.*, 1975) and the efficacy of these approaches has yet to be established.

OVERVIEW

Tooth movement in response to orthodontic forces involves bone remodelling. This relatively simple clinical procedure involves complex biologic processes that are not yet well understood. The response involves transduction of the mechanical stimulus to cellular biochemical processes and various modes of transduction have been suggested. The role of electric streaming potentials is not clear. Membrane proteins provide a means of communication from the extracellular matrix to the intracellular environment. Biochemical mediators, including cytokines and eicosanoids, appear to have intimate roles in bone remodelling and allow for local regulation. Thus, bone remodelling involves mechanical, neural, electrical, humoral and local biochemical events. We have only begun to scratch the surface into obtaining an understanding of tooth movement, and certainly, earlier proposals such as the tension-pressure hypothesis, are no longer consistent with the available evidence. As our understanding develops the field of clinical orthodontic pharmacology will evolve, and in the future we are likely to see the advent of agents to be used as adjuncts to mechanotherapy.

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16
Prediction Tracing & Treatment Planning for the Surgical Orthodontic Case

Paul Taylor

HISTORY AND BACKGROUND OF PREDICTION TRACING

Since Charles Tweed (1954) first presented his diagnostic triangle, many orthodontists have used cephalometric tracings, not only to help analyse cases, but to also establish precise cephalometric treatment objectives.

Several authors, including Steiner (1959), Holdaway and Bench, Gugino, Hilgers (1977), have all developed this concept. Holdaway in particular has presented a step by step procedure for developing an overlay prediction tracing for the patient who requires orthodontic treatment. His prediction tracing takes into account soft tissue harmony, stability of the dentition and likely growth increments. Holdaway called this prediction tracing "The Visualised Treatment Objective" or VTO.

More recently, Wolford and others (1985) have utilised the VTO in surgical-orthodontic planning. *Wolford coined the term STO which means* the Surgical Orthodontic Treatment Objective.

The main reasons for doing prediction tracings for the prospective surgical/orthodontic are as follows:

a. It enables the orthodontist to plan tooth movements taking into account the need for extractions and likely mechanics.
b. It enables surgeons to determine the type of surgery to be done and the exact nature of the osteotomies.
c. It provides a basis of communication between orthodontist, surgeon and patient.
d. It provides a basis for self-assessment for both the orthodontist and surgeon at the completion of treatment.
e. It provides a basis for splint construction.
f. It gives a reasonable prediction of soft tissue changes that can provide a basis for computer imaging work.

For all of the above reasons, prediction tracing has come to be a most important diagnostic tool in surgical-orthodontic case management. Nonetheless, in order to diagnose a patient, one still need to use the surgeon's and orthodontist's knowledge regarding the limitations of their respective treatment, which is gained from clinical experience, and will determine much of the overall treatment plan. The STO, however, provides an excellent means for fine tuning the details of the diagnosis.

This chapter details a step by step procedure for the construction of STO's. The reader is referred to chapter 6 for further explanation of cephalometrics.

DEFINITION OF TERMS

Before beginning the step by step procedure of constructing an STO, it is important to define terms that will be used throughout the rest of the chapter:

1. **VTO** - (Visualised Treatment Objective) is a prediction tracing employing orthodontic tooth movements alone. Such a tracing can be of help in determining which cases should be treated by an orthodontic approach versus an orthodontic and surgical approach.
2. **Initial tracing** - this is a tracing of a patient's lateral skull head film showing the following anatomical detail:
   a. Soft tissue profile.
   b. Sella.
   c. Nasion.
   d. Orbitale.
   e. Porion.
   f. Maxilla including all teeth.
   g. Mandible including all teeth.
3. **Modified CT** - (Modified Cephalometric Tracing) is a diagram of the patient which is based on the initial tracing. It shows:
   a. Basic anatomical detail.
   b. Ideal incisor and molar orthodontic repositioning with associated soft tissue changes.
   c. Construction lines which are used to help reposition the teeth and construct the STO.
4. **Initial STO** - this is an overlay tracing derived from the modified cephalometric tracing. It shows bony and soft tissue changes required for the correction of a malocclusion employing both orthodontics and surgery. It represents the final ideal repositioning of the teeth, bones and soft tissue at the completion of orthodontic and surgical treatment.
5. **Modified STO** - this incorporates the minor over movements of the teeth required prior to surgery in accordance with the type of malocclusion being treated.
6. **Masto** - (Mechanical and Surgical Treatment Objectives) is a statement of the mechanical and surgical needs of a patient. It is done on a clear piece of plastic which is attached to the patient's card and needs to be referred to frequently throughout treatment.
7. **Final STO** - (Final Surgical Treatment Objective). This is an overlay prediction tracing which is done immediately prior to carrying out surgery. All presurgical tooth movements have been completed.

In summary the overall steps from when an initial tracing is done of the patient until treatment has been completed are:

Initial Tracing
↓
Modified CT
(3 Steps)
↓
Initial STO
(Maximum 7 steps + review of tooth movements and soft tissue changes)
↓
Adjustment of STO for Pre-surgical Over Movement of Teeth
↓
Modified STO
↓
Masto
↓
Pre-surgical Orthodontics
↓
Final STO
↓
Sugery
↓
Post-surgical Orthodontics
↓
Completion of Treatment and Retention
↓
Case Review

THE SKELETAL SEVERITY FACTOR ANALYSIS

The skeletal severity factor analysis is applied to all patients and used as an adjunct in the differentiation of surgical and non-surgical cases. This analysis is based on three readings.

1. The WITS discrepancy.
2. McNamara's mandibular-maxillary differential subtracted from 20.
3. Projection of "A" and "B" points onto the Frankfort Horizontal.

These three measurements are totalled when the result lies outside the range -20mm to +20mm then the case is generally best managed by a combined surgical/orthodontic approach.

CASE EVALUATION

To demonstrate the clinical application of case selection and management of pre-treatment cephalometric radiographs a case evaluation for patient RC follows. A combined surgical/orthodontic approach to treatment was arrived at for the following reasons:

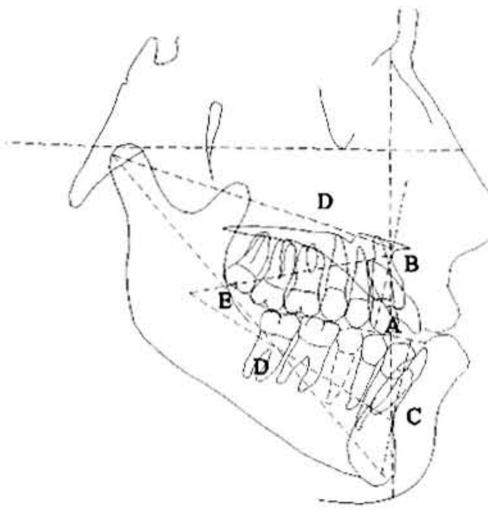
1. RC's twin sister had been treated with a combined surgical/orthodontic approach. RC had been very pleased with the result that had been achieved for her sister.
2. A skeletal severity factor analysis when applied to RC gave a result of -27mm as follows:
   - The WITS discrepancy, was -9mm.
   - A differential factor which is derived from subtracting McNamara's mandibular-maxillary differential from 20. In RC's case, the differential was 37mm and, therefore, when it was subtracted from 20, this differential rating was -17mm.
   - Projection of A and B Point onto Frankfort Horizontal, this measured -0mm.
   - When these three measurements are added together RC's skeletal severity factor becomes -26mm, which lies outside the range -20mm to +20mm and, as such, RC can be best managed by a surgical/orthodontic approach.

Cephalometric analysis *(Fig. 1)*

Cephalometric analysis involves investigation the following measurements:

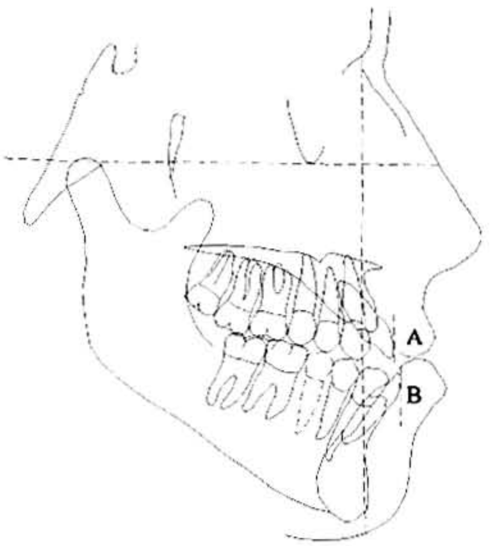
1. WITS
2. LFH
3. Perpendicular through Na
4. A Perpendicular, B Perpendicular to Frankfort Horizontal
5. McNamara's Assessment

Fig. 1. A - Facial and intra-oral views



	Measurement	Value
A	WITS	-9mm
B	A to Na perpendicular	0mm
C	B to Na perpendicular	0mm
D	Mand/max differential	37mm
E	Lower face height	45°

Fig. 1. B - Skeletal measurements used for cephalometric analysis.



	Measurement	Value
A	Upper 1 to Na perpendicular	7mm
B	Lower 1 to Na perpendicular	9mm

Fig. 1. C - Dental measurements used for cephalometric analysis

Construction of Modified Construction Tracing

Step 1 - Basic Anatomical Detail (Fig. 2)

Basic anatomical detail derived from the initial tracing is transferred to a white piece of paper using a photostat machine. If there is no

photostat machine, then this can be simply retraced using a view box. If you are retracing it, is best to use a fine felt pen; for the modified cephalometric tracing a black pen is required.

If the lateral skull x-ray has been taken with the lips together rather than in a relaxed posture, it is best to relieve the lip strain at this stage. This will usually mean slight eversion and lowering of the lip and a slight thickening of the chin point.

At this stage, add the Frankfort Horizontal which is based upon the patient's natural head posture when the x-ray is taken. (see chapter 6).

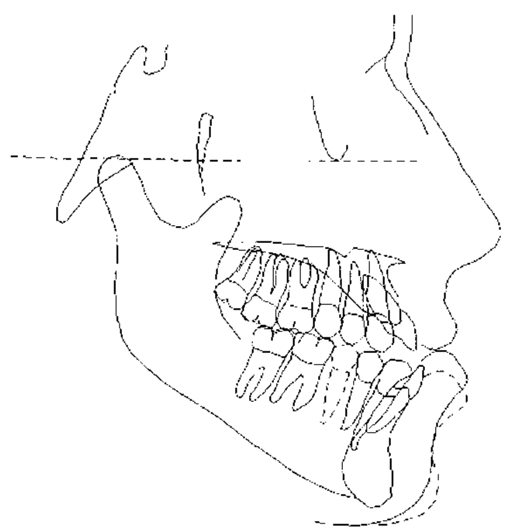


Fig. 2. Basic anatomical detail showing eversion of lower lip and thickening of chin point.

Step 2 - Repositioning Teeth and Soft Tissue. (Fig. 3)

General principles appear as Appendix 1 - Tooth Repositioning

In order to reposition teeth:

1. Draw lines through A-Point and B-Point running perpendicular to the Frankfort Horizontal (in this case the lines almost coincide).
2. Draw the functional occlusal plane.
3. Reposition the upper central incisors to lie 4mm in front of the A perpendicular line with the apices of the teeth centred in the alveolar trough. Likewise, reposition the lower incisors 4mm in front of the B perpendicular line again with the apices of the teeth centred in the alveolar trough. The incisal edges of both upper and lower teeth should rest on the functional occlusal plane.
4. Reposition overlying soft tissue with the upper lip retracting two thirds of the upper incisor retraction. Note the upper lip elongates one third of the amount of upper incisor retraction. The lower lip retracts on a 1:1 basis relative to lower incisor retraction.
5. Molar repositioning based upon incisor relocation in Steps 1 to 4, the amount of crowding, levelling and extractions required.

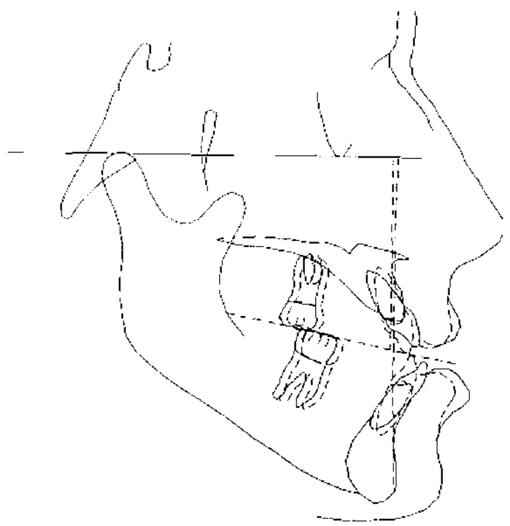


Fig. 3. Repositioning of teeth and soft tissues.

In patient RC's modified cephalometric tracing, after the upper and lower incisors had been moved to their corrected positions with

regard to the A perpendicular, B perpendicular lines. The space required for the retraction of anterior teeth requires the extraction of all four first premolars. These measured 7mm in width. The upper incisors need to be retracted 3.5mm and with 3mm crowding in the upper arch, the upper molars will come forward approximately 2mm during the course of orthodontic treatment.

The lower incisor teeth need to be retracted 4mm and with 2mm of lower arch crowding, only 2mm would be occupied by bringing the molars forward, out of the 2mm extraction space. The upper incisal edges are brought vertically to the level of the molar and premolar tip by simple retraction. The apex will not be extruded, in fact, intrusion is necessary. With the lower arch, direct horizontal retraction of the lower incisorsn maintains the tip of the incisors on the same plane as the molars and premolar teeth.

Step 3 - Adding Construction Lines (Fig. 4)

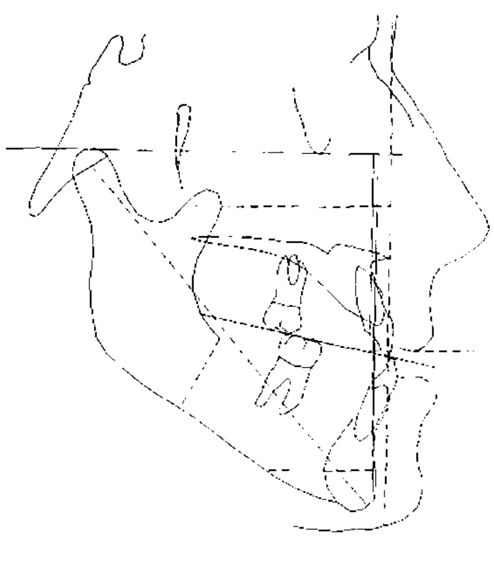


Fig. 4. The Completed Modified CT showing construction lines added.

Four construction lines are added at this stage:

1. The facial perpendicular to Frankfort Horizontal based upon an assessment of patient's midfacial aesthetics. (See Appendix IV)
2. Upper incisal edge line. (See Appendix III)
3. Condylar axis to gnathion.
4. Proposed osteotomy line(s). Add a line for a Le Fort 1, a sagittal split and a genioplasty.

Establishing the appropriate facial perpendicular line and upper incisal edge lines are the most important steps in the construction of the modified cephalometric tracing. These will determine the horizontal and vertical repositionings of the anterior portion of the maxilla when the STO is being constructed. For this reason, appendices have been drawn up showing the various factors that need to be taken into account in the construction of these lines. (See Appendix II and IV).

A bimaxillary procedure was predicted for RC for the following reasons:

1. There is an excessive mandibular length indicating the need for mandibular setback.
2. The open bite present requires maxillary impaction in order to achieve a positive overbite.

A genioplasty is also considered to allow adequate lip seal and function. The decision about the genioplasty, however, is not made until the final step of the STO construction as will be shown.

With regard to the positioning of the perpendicular line in patient RC's case, it was thought that there was a mild retrusion and, therefore, this perpendicular line should be drawn 2 to 3mm in front of the current

A-Point. With regard to the incisal edge line, it was thought that RC had an ideal display of upper incisor pre-treatment. It was also taken into account that there would be slight lengthening of the lip due to orthodontic retraction, this would be virtually cancelled out by the later maxillary advancement. It was, therefore, thought that the pre-treatment vertical position of the upper incisor was almost ideal and, therefore, the upper incisal edge line was drawn at this level.

Construction of the STO

Once the modified cephalometric tracing has been completed, a second sheet of paper is taken and placed on top of the modified cephalometric tracing. In overlay tracing, work is done on a viewer box. Tracing for the STO is generally done with a fine tip red pen. The STO construction will apply to RC.

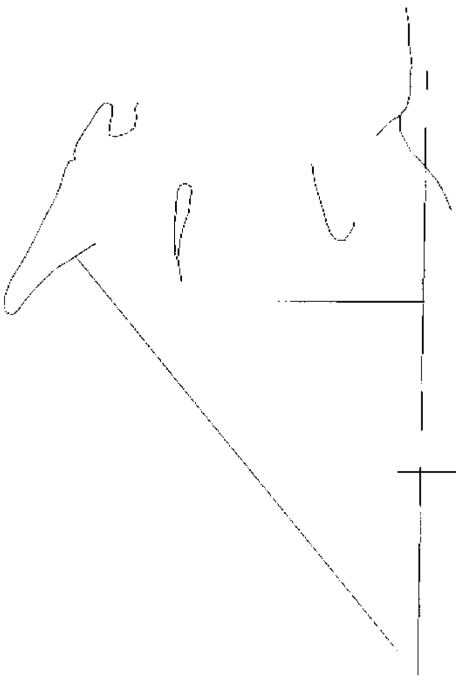


Fig. 5. Stable structures and construction lines.

Step 1 - Trace all Stable Structures and Construction Lines (Fig. 5)

With the construction of the STO, the A perpendicular and B perpendicular lines and occlusal plane lines are not transferred to the STO as these were simply placed originally to help us relocate the upper and lower incisors. The mandibular osteotomy lines are also not placed on the STO, at this stage.

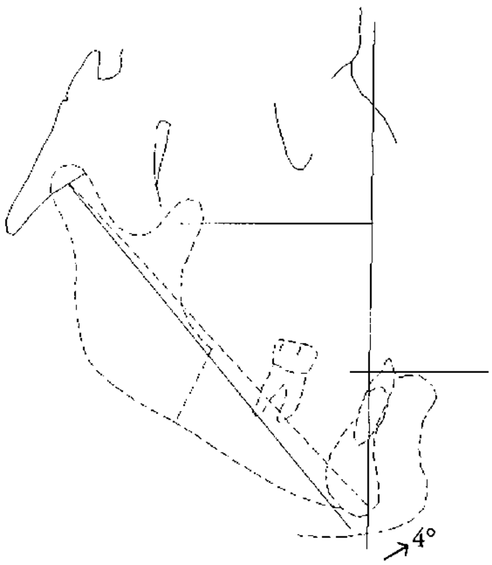


Fig. 6. Autorotation of the mandible.

Step 2 - Autorotation of the Mandible (Fig. 6)

The overlying STO is superimposed on the condylar axis point and rotated until the underlying lower incisor lies 2mm above the upper incisal edge line on the STO sheet. This represents a normal overbite relationship. Having rotated the STO in this fashion, the mandible is then traced in, including soft tissue, the new condylar axis to gnathion line plus mandibular osteotomy cut lines.

This is a most important step in that it determines the amount of posterior maxillary impaction that will be required in Step 3.

Step 3 - Maxillary Repositioning (Fig. 7)

The overlying tracing is now moved so that the underlying modified cephalometric tracing is repositioned with the upper molars showing no vertical overlapping with the lower molars. The upper incisal edge should rest on the upper incisal edge line on the STO sheet. With regard to horizontal repositioning, the maxilla is moved so that A-Point is now 1mm in front of the facial perpendicular line.

Once having repositioned the maxilla in this way, the new maxillary position is traced in including the new maxillary osteotomy line. Measurements are entered into the STO to show how much impaction and advancement occurs both posteriorly and anteriorly.

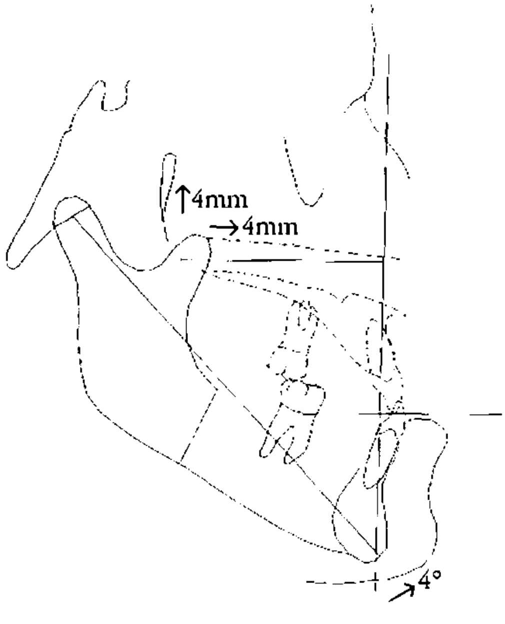


Fig. 7. Maxillary repositioning.

Step 4 - Maxillary Soft Tissue Repositioning (Fig. 8)

For changes in the soft tissue, the results of the maxillary advancement are as follows:

The upper lip will come forward two thirds of the maxillary advancement and up one third of the advancement distance. For example, in a patient who has a 6mm advancement, the soft tissue lip will come forward 4mm. At the same time, the upper lip will go up 2mm. The soft tissue of the upper lip is drawn in accordingly. The overlay tracing is then repositioned on the cranial base structures. The soft tissues from the top of the lip to the Frankfort Horizontal is then traced in on a diminishing return basis.

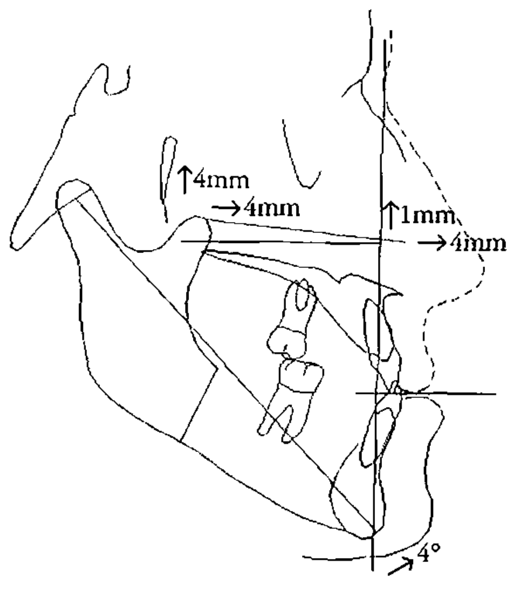


Fig. 8. Maxillary soft tissue repositioning.

This means that by the time the soft tissue reaches the Frankfort Horizontal plane, there is no effect either vertically or horizontally of bringing the maxilla forward. The maximum effect is at the lip; the minimum effect is at the Frankfort Horizontal plane. There is a degree of artistic licence required in the drawing in of the nose and lip soft tissue using this method. (See Appendix III).

Step 5 -Mandibular Repositioning

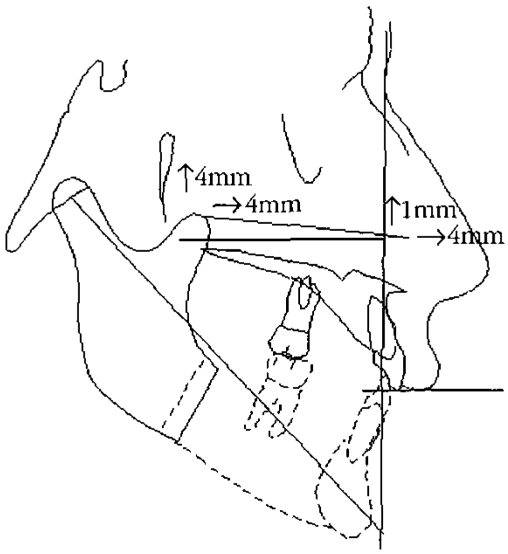


Fig. 9. Mandibular repositioning.

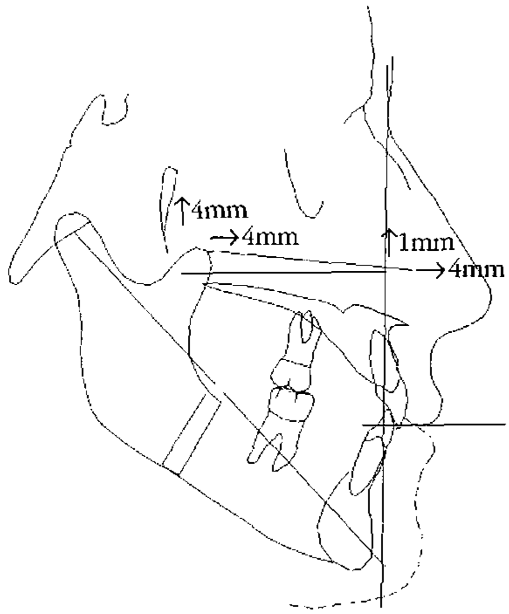


Fig. 10. Mandibular soft tissue repositioning.

A third sheet of paper is now required for the completion of the STO. The cranial base is traced onto this third sheet of paper by overlaying it on the original modified ceph tracing. The original ramus position of the mandible is also traced in. The modified ceph tracing is then removed and the second sheet of paper showing Steps 1 through to 4 is placed underneath sheet number 3. The maxilla and the overlying soft tissues with the osteotomy line shown and then traced in.

The mandible is now traced in an ideal Class I relationship. This is the time at which the stability of mandibular movement can be reassessed. The lower border of the body of the mandible should not be longer than the lower border of the original ramus position.

Step 6 - Mandibular Soft Tissue Repositioning (Fig. 10)

Generally, the mandibular soft tissues will follow the hard tissue on a 1:1 basis.

Step 7 - Genioplasty

At this stage, it was considered in the case of patient RC, a genioplasty was not necessary because good soft tissue balance was achieved by the osteotomy movements bringing the lips into contact vertically and achieving an ideal soft tissue balance. However, if such a step is necessary, then the overlay tracing is moved in such a way as to bring the chin point into an ideal position and this is then traced onto the STO with associated changes in the overlying chin soft tissue.

REVIEW STEPS *(Fig. 11)*

Once the STO has been completed, two important review steps are necessary.

1. Because the movement of the jaw has the potential of moving the teeth away from the ideal relationship relative to A and B perpendicular, it is important that these lines be redrawn on the STO,

at this stage, and incisor positions reassessed. In the case RC, it was noted that the upper incisor was slightly over retracted due to the effect of the posterior maxillary impaction. The u pper incisor needs to be slightly proclined to make adjustment for this. This adjustment of tooth position in accordance with osteotomy movements is one of the most significant advantages of STO construction.

2. Ensure that the soft tissue contours are in harmony. In order to do this, the Holdaway (1983) method of soft tissue analysis is applied to the patient. In RC's case, all of the measurements fell within the ranges established for normality by Holdaway.

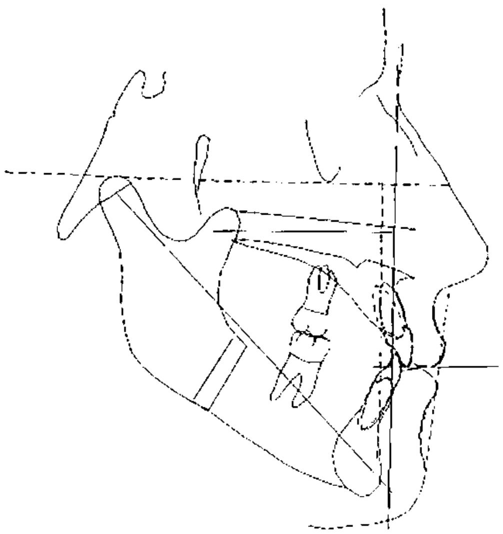


Fig. 11. Review of STO

Adjustment of Teeth in Accordance with Modified STO *(Fig. 12)*

With certain surgical procedures, there is a degree of relapse after the operation. It is therefore important that certain over-movements be carried out. Specifically with Class III problems, after a mandibular set back even since rigid fixation methods have been employed, the mandible comes forward. This is probably due to the condyle being pushed posteriorly during the surgical procedures and that once surgery is over, the condyle comes anteriorly. In order to compensate for this, the upper incisor teeth should be retracted 1 to 2 mm further than their ideal position and that the lower incisors be set 1 to 2mm forward of their ideal STO position. These slight alterations are shown in the modified STO tooth repositioning.

After taking these minor alterations into account, the modified cephalometric tracing provides the basis for the mechanical and surgical objectives.

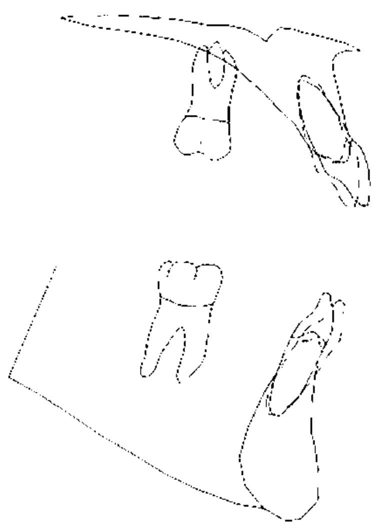


Fig. 12. Tooth adjustments to allow for relapse.

The Mechanical and Surgical Treatment Objective - Masto

Figure 13 (a) is a standard MASTO form before being filled in. Figure 13 (b) is the MASTO form for patient RC which is a summary of the extraction, osteotomy and

orthodontic requirements. This information is derived from the modified CT and STO.

The following steps were taken in filling in the MASTO form:

1. It is clear that RC will require extractions given the amount of retraction required. The non-extraction option is therefore crossed out.
2. In view of the retraction required in each arch, the removal of all first premolar teeth is required.
3. Based on the initial STO, maxillary and mandibular surgery is required but that splitting the maxilla, genioplasty, or segmental procedure is not necessary. The last three options are then crossed out.
4. From the initial STO, the posterior end of the palatal plane is raised 4mm and advanced 4mm while the anterior portion is advanced 4mm and impacted 1mm. These figures are entered on the diagram.
5. The ramus auto-rotates closed 4°.
6. A 6mm set-back of the body of the mandible is required.
7. The dotted lined teeth represent the central incisors and the first molars after pre-surgical orthodontics has been completed.
8. The grid diagram represents the ideal lower arch form. The lower premolars and molars need some expansion to bring into the correct transverse relationship with the upper buccal segments. This is based on moving the upper and lower casts into a Class I molar relationship. This expansion of the lower arch is very often needed as part of the transverse decompensation of Class III cases.
9. A brief statement of mechanics establishes the pre-surgical plan. In RC's case, the upper molars can afford to come forward minimally and therefore maximum anchorage is required. The apex of the incisors need intrusion; therefore strong tip-back mechanics will ensure that both of these goals are attained. In the lower arch, the molars could come forward slightly more and therefore the lower anteriors could be retracted on a round wire with a reverse curve of Spee to ensure anchorage and vertical control of the lower anteriors using Edgewise brackets. Just prior to surgery, the lower arch will be stabilised on a 0.017 x 0.025 archwire shaped to the form shown on the grid.
10. Special consideration: In RC's case the OPG shows upper third molars, but the lowers are missing. As the upper third molars were already erupted, it was decided to not remove them at the time of the surgery, but to review them after orthodontic treatment was completed.

All this information is concisely entered on the MASTO which is a plastic slip attached to each surgery patient's card.

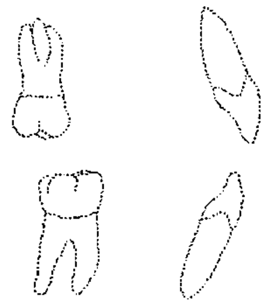
Treatment results

Summary (Fig. 14)

By following the above steps, a concise treatment plan can be established on the MASTO. Pre-surgery cephalometric radiographs are needed at the completion of pre-surgical orthodontics to check the tooth positions established in the modified STO. A new STO is then constructed based on the actual tooth positions achieved. This STO is the final STO. At the completion of treatment, it is important to take another radiograph to test accuracy of the predictions. In RC's case, the initial STO and post treatment tracings are shown in Figure 14.

ORTHODONTICS

NON
EXO



SURGERY

Maxilla (split)
Mandible
Segmental
Genioplasty

MAXILLA

MANDIBLE

Arch Form

MECHANICS

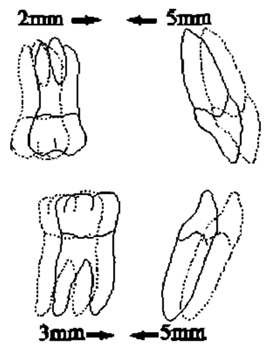
SPECIAL CONSIDERATIONS

Fig. 13. A - Standard Masto form.

ORTHODONTICS

NON
~~EXO~~

4	4
4	4



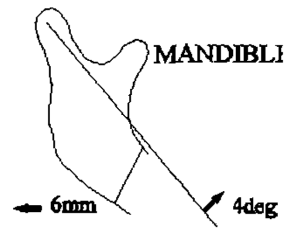
SURGERY

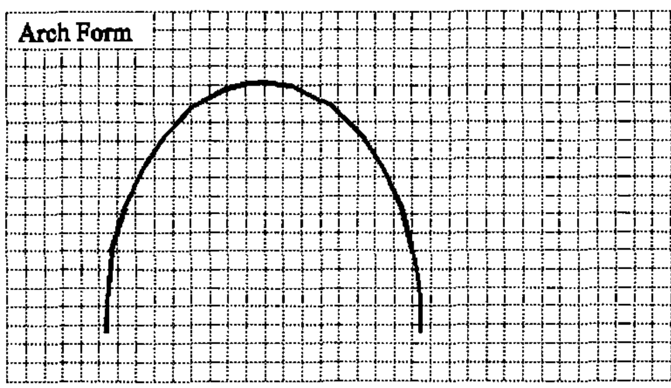
Maxilla ~~(split)~~
Mandible
~~Segmental~~
~~Genioplasty~~

MAXILLA

↑ 4mm ↑ 1.00mm

4mm → 4.00mm →





Mechanics

CAT - Appliance
U - Maximum anchorage
L - Maximum anchorage
Pre-surgically wires, 0.017 x 0.025 upper and lower

Special Considerations

Possible removal of upper 3rd molars after treatment is completed.

Fig. 13. B - Completed Masto form.

The STO shows less posterior impaction of the maxilla occurred than was predicted. This may be because there was less molar extrusion when closing the lower extraction spaces and therefore less need for posterior impaction.

Overall, it can be seen that the initial STO was a reasonable predictor of the ultimate outcome of treatment. Reviewing cases with an STO is an excellent means of self assessment.

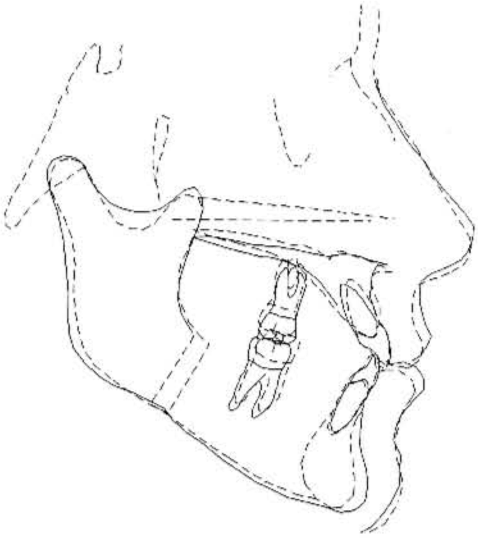


Fig. 14. A - Comparison of STO (dotted) and final results (solid).

Fig. 14. B - Post surgical new.

APPENDIX I

Tooth Repositioning

The general principles of tooth positioning here are related to the patient RC.

Anterior/posterior repositioning of molars and incisors.

The incisor teeth are the first teeth to be repositioned in the modified cephalometric tracing. After they have been adjusted, molar horizontal movement is then adjusted to satisfy arch length requirements, that is crowding, spacing and levelling.

The rules of incisor repositioning, shown *(Fig. 15)*, are as follows:

1. The upper incisor is adjusted to the 4mm in front of the A perpendicular line with the apex centred in the alveolar trough.
2. The lower incisor is situated 4mm in front of the B perpendicular line, again, with the apex centred in the alveolar trough.

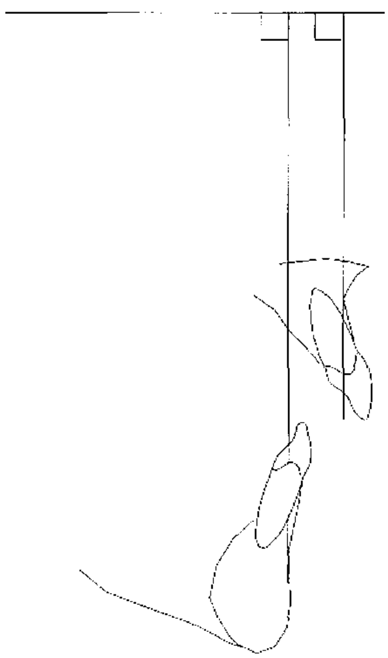


Fig. 15. Showing the measurement of the labial face of upper and lower incisor teeth relative to A and B perpendiculars.

A) Levelling Curves of Spee with Reduced Lower Facial Height.

If the lower facial height is reduced below 47°, the arch is levelled by drawing a line from the incisal tip to the highest point in the posterior region. Generally this is marked by the distobuccal cusp of the twelve year old molar *(Fig. 16)*.

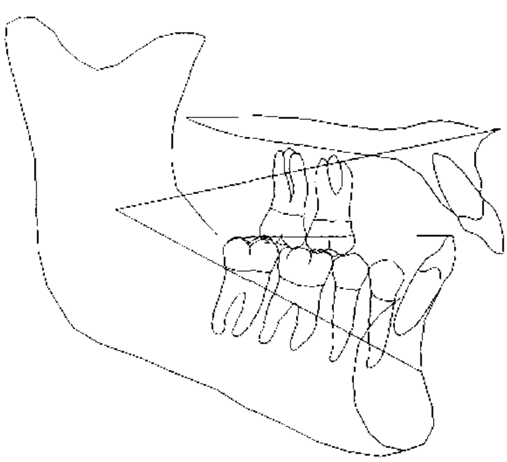


Fig. 16. Levelling of curve of spee with reduced face height.

In the STO, the molar and premolar teeth will be brought up to this level. When arches are to be level, there is an increase on a one-to-one basis in arch length requirement; that is, if we need to level a Curve of Spee by 3mm, this will acquire an increased 3mm of arch space to gain such levelling.

With Class III cases, there is often a need for lower arch expansion as well as levelling. Therefore arch levelling does not express itself on a 1:1 basis but rather in a 2:1 ratio. If the curve is levelled 3mm, there is a need for an extra 1.5mm of arch length.

B) Levelling Curves of Spee with Increased Lower Facial Height

If there is a deep Curve of Spee, and the patient has an increased lower facial height, the functional occlusal plane is used as an

indicator of the level for adjustment of incisor position. The incisors will need to be either intruded by orthodontic means or by a segmental surgical procedure (Figure 17). Again the same effects on arch lengths will occur as mentioned previously in section a.

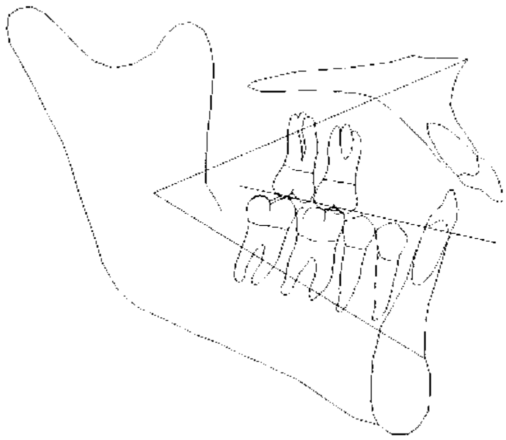


Fig. 17. Levelling curve of spee with increased face height.

C) Levelling Curves of Spee with Normal Lower Facial Height

In such cases, the levelling of the Curve of Spee will be brought about by a combination of slight molar and premolar extrusion and lower incisor intrusion (Figure 18).

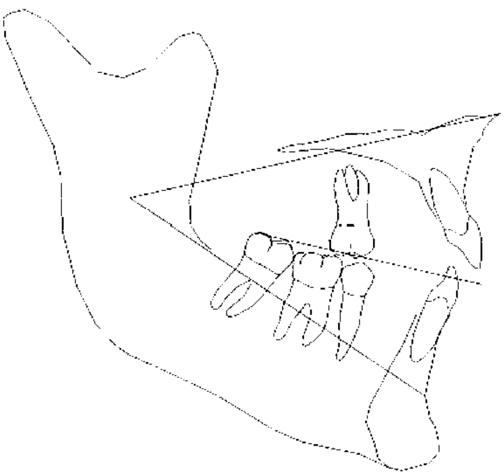


Fig. 18. Levelling curve of spee with normal face height.

Levelling of Reverse Curves of Spee

The level for incisor repositioning is established by drawing a line through the tips of the six year old molar and bicuspid teeth (Figure 19).

If the upper incisors need to be retracted for preparation of the arches, and if this retraction results in lengthening of the incisal edge to a line drawn through the tips of the cusps of the molars and bicuspids and does not result in any apical extrusion, then the levelling is done by an orthodontic approach alone. If such levelling does require extrusion of the teeth at its apex, then such arch levelling would involve a segmented surgical approach. In such cases, the arch or arches will need to be set up on a split level, that is with a step-up arch and the surgeons at the time of surgery will level the arches by differential impaction of the posterior and anterior segments.

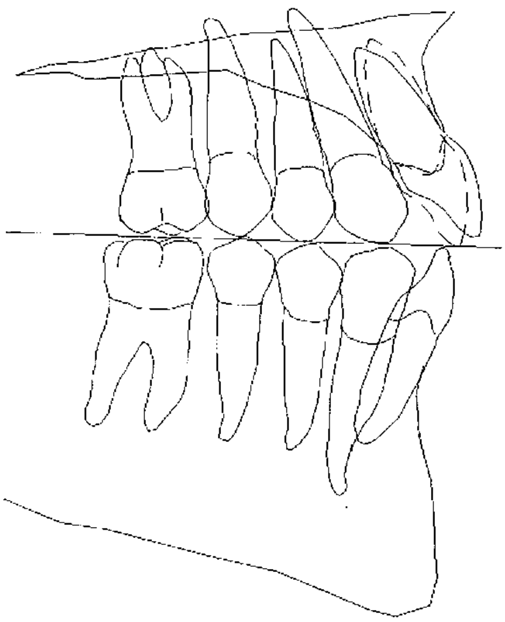


Fig. 19. Levelling a reverse curve of spee when tooth extrusion is not required.

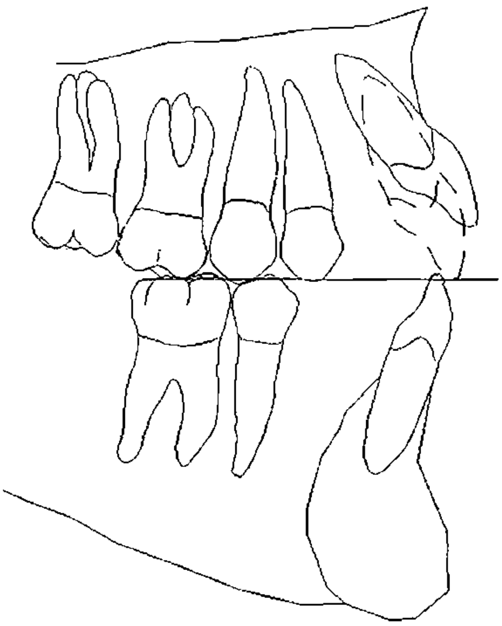


Fig. 20. Levelling a reverse curve of spee when tooth extrusion is required.

APPENDIX II

Upper Incisor Edge Line

When determining the position of the upper incisor edge line, the following factors need to be taken into account:

1. The current relationship between the upper lip and edge of the upper central incisors.

   When evaluating the current relationship between the lip and the edge of the incisors, the patient should be assessed with their lips at rest, with a moderate smile and with an exaggerated smile.

   This information can really only be established by careful examination of the patient. The lateral skull radiograph often is unreliable as the patients may take a strained position while the radiograph is being taken. If we are to use lateral skull radiographs at all to evaluate the position of the upper incisor relative to the upper lip, it is vital that this radiograph be taken with the patient's lips in a relaxed posture. The patient should not make any efforts at all to achieve lip seal if this does not come comfortably. It is generally accepted that a patient who has a normal lip length will expose 2mm of their upper incisor at rest. If the patient exhibits a broad smile, there should be no more than 2mm of exposure of the upper gingival tissues.

2. The current lip length from the lip to the base of the nose.

   The average lip length from the base of the nose to the edge of the lip is 22mm. If there is normal length, then the exposure of the upper incisors should be 2mm. If however, the lip is shorter than 18mm, then it is appropriate for there to be an increased exposure of the upper incisal edge. It is important not to adjust the dentition to an aberrant lip length. Conversely, if the current lip length is greater than 26mm, usually there is less exposure of the incisal edge; usually only approximately 1mm in apparent.

3. The tooth movements required in both the horizontal and vertical planes.

   Generally, with direct horizontal retraction of upper incisors, the upper lip retracts two thirds of the maxillary movement. That is, if we were to retract the upper incisors 3mm the lips would come back only 2 of those millimetres. Often, however, in our orthodontic levelling, the upper incisors do not come back in a direct horizontal manner but there will be seen to be a lengthening is on a 1:3 basis. This must

be taken into account in the initial STO construction. Retraction of the lower incisor usually results in a 1:1 retraction of the lower lip.

4. Likely horizontal maxillary repositioning.

   The soft tissues show considerable variability in their response to maxillary movement. As a rule of thumb, for every 3mm the maxilla is brought forward, the upper lip will go up 1mm. Similarly, for every 3mm of impaction, the upper lip will go up 1mm. *(Fig. 20)*.

5. Patient preference.

   This is clearly most important. As a general rule patients with a vertical maxillary excess should be left with a slight vertical excess.

APPENDIX III

Soft Tissue Changes

The technique employed for adjusting the soft tissue from a maxillary advancement is to divide the distance between the pre-treatment and surgically positioned incisal edge into thirds. These thirds are a division not only horizontally but also vertically.

To do the tracing of the upper lip, leave the onlay tracing so that the new incisal edge has been raised one third positioned horizontally two thirds towards the initial tracing. Once the incisal edge has been placed in this position, the new upper lip is placed. The rest of the soft tissue is drawn in on a diminishing return basis.

This means that by the time Frankfort Horizontal is reached, the soft tissue changes are nil. *(Fig. 21)*.

With repositioning the mandible, the soft tissue covering the chin usually comes back on a one-to-one basis. If the lip has been in a relaxed posture, the lip will also move on a one-to-one basis. Sometimes, however, with both Class II's and Class III's, the lower lip posture has been significantly affected by the current negative or positive overjet. In such cases, the best way of tracing the new lower lip form is to superimpose the new interincisal position on the pre-treatment interincisal position, then trace in the lip. This gives a reasonable prediction of the lip changes that will occur.

APPENDIX IV

The Facial Perpendicular

A decision about the horizontal position of the middle facial third is primarily decided upon by facial examination. Factors taken into account are:

1. The width of the alar bases.
2. Prominence of the cheeks.
3. Nasiolabial angles.
4. The chin to neck length.
5. Shape of the nose.
6. The type of malocclusion.

If after looking at a patient it is decided that a maximum advancement of the maxilla will be required, then the facial perpendicular is drawn 5 to 6mm in front of the current A-Point. If a moderate advancement is required, then the facial perpendicular drawn 3 to 4mm in front of the current A-Point. If a mild advancement is required then the facial axis is drawn 2 to 3mm in front of the current A-Line. Of course, if the maxilla horizontally is in the ideal position, then the facial perpendicular is drawn 1mm behind the current A-Point.

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17
Class II Malocclusions

John D Jenner & John P Fricker

INTRODUCTION

Dr Begg (1972) refers to the terms **"differential force" and "light wire technique,"** a new technique with a radical departure from other techniques of orthodontic treatment. He pointed out that this technique provided common ground for agreement between the school of thought advocating movement of tooth roots to their correct relations and the school advocating light forces. The school using rectangular arch wires provided correction of faulty axial relations of teeth but they required extra oral forces to provide adequate anchorage. The other school used round wires and lighter forces with less anchorage demands but inadequate control for correcting faulty axial relations particularly where extractions were required. Dr Begg claimed that the lightwire differential force technique was a synthesis of the better elements of both techniques. He stated "Higher standards of treatment are attainable, even in severe malocclusions which previously were treated to a compromise.

The Begg lightwire technique evolved as a means of more efficiently and effectively moving teeth through bone. Over the years these methods of tooth movement have been refined and improved such that they have been adopted by most of the major techniques in orthodontics today. This sharing and interplay between all techniques is acknowledged as a healthy means of improvement of individual techniques. There seems little doubt that Dr Begg was preoccupied by moving teeth through bone rather than influencing the jaws in the way that we now refer to as orthopaedic. Clinical case reports illustrating treatment with the Begg - Lightwire technique clearly reflect a combination of tooth movements through bone as well as orthopaedic influence in the jaw relations. However, it is evident by examination of many of the treated cases of that era, that over retraction of anterior teeth was considered a necessity to allow for the later mesial migration of teeth as well as the anchorage demands in treatment. In writing about the 3 stages of treatment in the Begg technique, Begg and Kesling (1977) write

"It is chiefly with the object of preventing anchorage failure, thereby ensuring efficient control of anchorage, that the technique is divided into 3 distinct stages of tooth movement."

Control of anchorage is just as critical today as it was when those words were written. However, we are now more concerned by the over retraction of anterior teeth that is possible with an appliance that is often too efficient in anchorage control. Furthermore, we have learnt that with the orthopaedic influences of fixed appliances, class 2 elastics and light forces we can now provide the growing patients with a much bigger range of treatment opportunities. For example, a full unit class II malocclusion may be treated to a class 1 where no arch spacing is available and a combination of orthodontic and orthopaedic treatments can be carried out simultaneously without the need for extractions, functional appliances or extraoral forces.

The great potential for fixed appliances to carry out such a broad range of Class II treatments should not prevent orthodontists from making use of other auxiliaries and appliances, particularly as functional appliances and extraoral forces provide more effective orthopaedic and orthodontic changes in some individuals. The challenge, is to accommodate a range of appliances in an efficient and effective way. In practice, this will frequently mean becoming an expert in several forms of treatment while avoiding the danger suggested by the description "jack of all trades, master of none".

DIAGNOSIS OF CLASS II MALOCCLUSIONS

The Class II malocclusion as classified by Angle (1907) is based on the mesial position of the maxillary first permanent molar relative to the mandibular first permanent molar and make up the majority of malocclusions which present for treatment (Keay *et al.*, 1993). Angle considered the maxillary first permanent molar the "key to occlusion". However the position of this tooth is a reflection of its relationship to the rest of the dentition and the skeletal base. When diagnosing a Class II malocclusion, one needs to assess the following relationships to the cranial base:

- Maxillary dental
- Mandibular skeletal
- Mandibular dental
- Vertical (Owen 1984)

Both a clinical examination and confirmation with cephalometric analysis are required in diagnosing the malocclusion and determining the areas where the discrepancies are expressed and those which require correction.

The anterior posterior relationships may be assessed as either a maxillary dental and or skeletal protrusive or mandibular dental or skeletal retrusive. Both these discrepancies will produce a convex profile. The greater the antero-posterior discrepancy the greater the overjet and the tendency to a lower lip trap. Such muscle activity may retrocline the lower incisors as the maxillary incisors are proclined. A partial lip trap has less of an effect on the lower incisors and will permit greater proclination of these teeth during treatment (Lew, 1991).

The cephalometric indicators of an antero-posterior discrepancy are the maxillary A point to SN and in the mandible, B point to SN. Generally an ANB angle of greater than 3° will indicate a Class II malocclusion with a skeletal component (Steiner 1953). (Fig 1) The Wits analysis is based on perpendiculars from points A and B to the functional occlusal plane (Jacobson 1975) along which the linear difference between these points is measured. If the anterior posterior positions of the jaws is in harmony, these two perpendiculars will intersect. The degree of skeletal disharmony in a Class II direction is estimated in millimetres as the distance A is in front of B. (Fig 2).

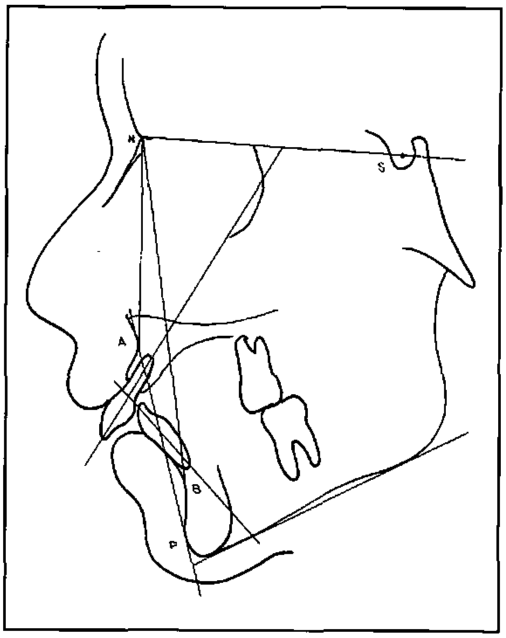


Fig. 1. Typical presentation of a Class II division 1 malocclusion

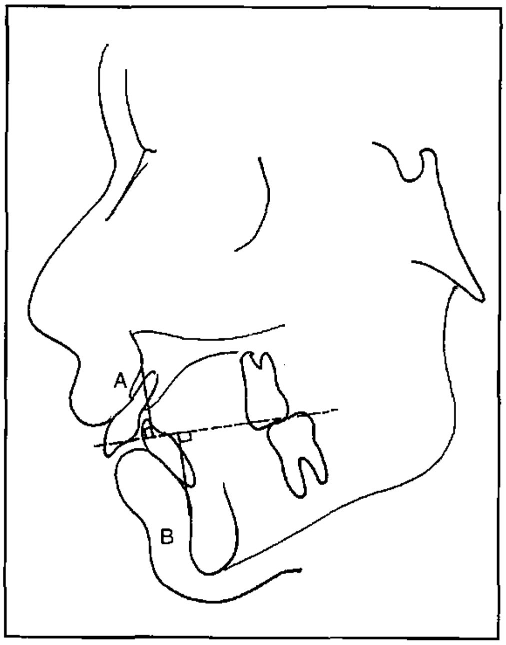


Fig. 2. "Wits" analysis - Vertical lines from points A and B to the occlusal plane will give a measure of the skeletal discrepancy between maxilla and mandible. In a balanced relationship, there lines will coincide to a straight line.

The angulation of the maxillary incisor to SN and the mandibular incisor to the mandibular plane, provide an assessment of dental protrusion or retroclination. Protrusion of the upper incisors leads to an increased overjet while protrusion of the lower incisors generally reflects a softer flaccid lower lip musculature. The SNA angle is normally 105° while the angle of the lower incisor to the mandibular plane is 90°. A line drawn from A point to Pogonion will provide further evidence of dental protrusion. Ideally the mandibular incisal edges should fall on the AP line. Where the incisors are ahead of the AP line the teeth are deemed in bi maxillary protrusion. Reduction of bi maxillary protrusion may require extraction of a premolar in each quadrant.

Class II malocclusions are further divided into Division I and Division II based on dental presentations.

The *Class II Division I malocclusion* is characterised by an increase in the overjet as a result of either proclination of the maxillary incisors or retroclined lower incisors. Often the mandibular incisors are over erupted producing a steep curve of Spee. Such dental components of the malocclusion may then be superimposed over the skeletal disharmony between maxilla and mandible (Owen 1984), such as a retrognathic mandible.

A *Class II Division II malocclusion* is characterised by retroclined upper and lower incisors and a large overbite. The clinical assessment is confirmed cephalometrically with reduced angles of the upper and lower incisors to SN and mandibular plane (MP) respectively and an obtuse interincisal angle. The lower incisors are generally behind the AP line and thus is reflected in a concave soft tissue profile. (Selwyn - Barnett 1991) (Fig 3).

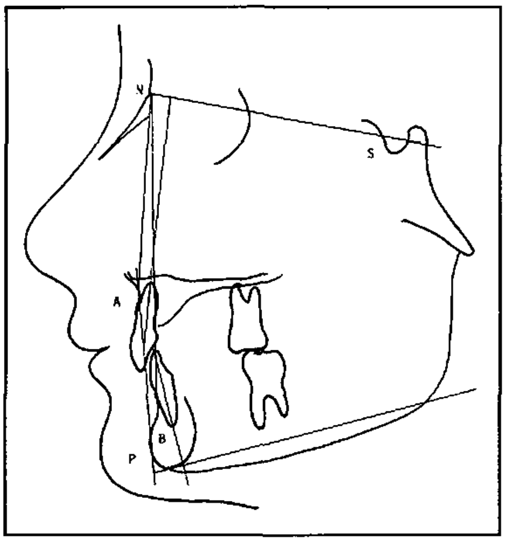


Fig. 3. Typical presentation of a Class II division II malocclusion.

Usually the mandibular plane angle is flat. The variables are thus the degree of skeletal discrepancy and the degree of crowding. The greater the degree of skeletal discrepancy, the more retroclined are the maxillary incisors. This is combined with a deepening of the overbite and traumatic occlusion between the gingiva of the palate and the mandibular incisors. The soft tissues of the lower lip will often show a deep labiomental groove which is an indication of an excessive overbite.

Most subjects with Class II Division II malocclusion have essentially normal skeletal pattern outside the immediate dental area and should not be considered like Class II Division I. Dentally the cephalometric measurements showed greatest differences in the angulation of the occlusal plane and the maxillary incisors. There is a short anterior face height which is combined with a relatively forward rotation of the mandible during growth.

A deep curve of Spee is associated with a more posterior position of B point and a greater interincisal angle, a deeper overbite and retroclined upper incisors. Thus the primary treatment objective in Class II Division II should be upper incisor intrusion with palatal root torque (Cleall and BeGole 1982).

It may be appropriate to start treatment with upper arch banding only to intrude the maxillary incisors, this will open the bite and provide clearance for brackets in the lower arch. An anterior bite plate may also be used to allow for lower molar eruption in these cases.

TREATMENT PLANNING WITH CLASS II MALOCCLUSIONS

Full Diagnostic records consisting of facial photographs, intra oral photographs, cephalometric tracing, panoramic film and study casts should be taken prior to undertaking any orthodontic treatment. These records should compliment the information collected from the clinical examination and a treatment plan developed. It is useful to develop a problem list (Proffit 1986) from the clinical examination and diagnostic records as a way of directing ones treatment plan. The visual treatment objective (VTO) is then prepared to direct one's treatment appropriately and avoid round tripping (Mollenhauer 1987).

Good forward and downward growth of the mandible is the single most important factor for stable overjet correction. (Hertzberg 1973) The rationale for orthodontic treatment is aimed at improvement in function, aesthetics and stability of the end result. The objectives of treatment are thus:

- Reduction of excess overbite.
- Reduction of overjet
- Relief of crowding
- Alignment of teeth
- Interincisal angle of 125-130°

- Class 1 canine relationship
- Support soft tissue profile and facial aesthetics

Every orthodontic correction should be fully integrated into both the facial type and the growth pattern of the patient being treated. Class II problems may be horizontal, vertical or a combination of both. The mandibular plane provides a key to the vertical relationship of the anterior segments. A flat mandibular plane is associated with a deep overbite, with a short lower face and brachyfacial pattern.

A steep mandibular plane is associated with an anterior open bite, long face and dolicofacial facial type (see cephalometrics). Vertical relationships at either end of the spectrum are difficult to treat with orthodontics only and consideration should be given to orthognathic surgery (see chapter 16).

TIMING OF TREATMENT IN CLASS II MALOCCLUSIONS

Orthodontic correction of Class II malocclusion may be either by way of intervention prior to the adolescent growth spurt to correct the incisor relationships both vertically and horizontally or with comprehensive treatment during the adolescent growth spurt between 12-15 years.

Usually early treatment will require a second phase of treatment as the remaining permanent teeth erupt (King *et al.*, 1990)

The most frequent skeletal problem in class II malocclusions in preadolescence is the retrognathic mandible (McNamara 1981) In these cases early treatment with functional appliances are indicated. Appliances such as the Clark Twin Block relocate the mandible into a protrusive position and direct continued growth into a harmonious facial balance (See chapter 14). The maxillary molars are stabilised and the mandibular molars permitted to erupt as the bite is opened, thus creating a Class I pattern in the buccal segments and reducing the need for extractions.

OVERBITE REDUCTION

Deep over bite malocclusion has been suggested as a factor in cranio mandibular disorders (Riolo *et al.*, 1987) and early reduction of overbite with orthodontic treatment will assist in the relief of these symptoms. (Hellsing 1990) has suggested the fitting of anterior bite plates to open molar contacts at the commencement of treatment. Once the molars are out of contact there is relaxation of hyperactivity. Early treatment with a removable Sved appliance will open the bite during the late mixed dentition. An anterior bite platform restricts the over closing of anterior teeth and encourages the eruption of both maxillary and mandibular molars. The use of bite plates is limited as vertical changes will usually be lost without class 2 correction. This, further treatment is usually required with fixed appliances to correct the occlusion and correct incisal angulations (See chapter 7).

EXTRACTIONS

The decision to extract or not to extract is based on the clinical data and the objectives of the treatment. Extractions are required where there is excess crowding. Traditionally the first premolars have been the choice, however, where there is a significant tooth size discrepancy extractions should be carried out in the area of crowding including the removal of a mandibular incisor (Ho and Freer 1994).

Arch expansion is an alternative to extractions and the decision to extract or expand is based on the diagnostic records

and the clinical assessment Borderline cases may suggest expansion, however, over expansion will produce and unstable result with an increased risk of relapse (see chapter 19).

Where there is an increase in overjet, either from dental protrusion or mild maxillary skeletal protrusion reduction of the overjet and camouflage of the skeletal discrepancy may dictate the need for premolar extractions to align the dentition to a class I canine relationship. Often a Class II malocclusion will present with a well aligned lower arch and the incisors are in good relationship with the lower lip, the AP line and to the mandibular plane. In these cases extractions are not indicated in the lower arch and maxillary first premolars are removed to provide space for the reduction of the overjet. The final occlusion is then aligned with a Class II molar relationship and a Class I canine relationship, the key to functional occlusion.

Curve of Spee

A steep curve of spee will (Fig 4) contribute to the increase in incisor overbite. As this is levelled, additional arch perimeter length is required and one has the choice of proclining the incisors or extractions. As mentioned previously, a good guide to proclination is the relationship of the lower incisor to AP. whether the incisor can be proclined forward of AP is qualified by clinical judgement of the muscles along the lower lip. Tight musculature will limit anterior movement of incisors as against more flaccid musculature which will allow greater stability of final positioning.

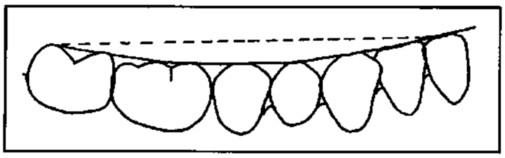


Fig. 4. Curve of spee - As the curve of spee is levelled, additional arch perimetes length is required.

Extractions may be either first or second premolars depending on the area of crowding and or anchorage requirements in the use of class II elastics. To achieve optimal facial balance the object should be to program the use of "differential anchorage" (Thompson 1982) such that teeth to be moved are adjacent to the extraction site while those teeth to be stabilised are grouped as a large anchorage segment as remote as possible from the extraction area.

In a mild Class II Division I case maxillary first premolars would be removed to provide space for the retraction of canines to a Class I canine relationship and alignment of the labial segment. Mandibular second premolars will stabilise the anterior segment of 8 teeth and permit the mesial movement of the first molars into the extraction sites placing them into a class I relationship.

Generalisations concerning the negative effects of extraction of first premolars are misleading. There is great individual variability in the effects of treatment yet the great majority of patients exhibit controlled amounts of profile change that produce improvements in facial aesthetics. (Drobocky and Smith 1989).

BITE OPENING WITH FIXED APPLIANCES

Overbite correction is carried out by means of intrusion of upper and lower incisors as well as elevation of mandibular molars. The magnitude of intrusive force depends on the displacement of the arch wire at rest in the labial sulcus to the bracket and the distance from the anterior portion of the arch wire to the molar tube (Xu *et al.*, 1994). As the anterior teeth are retracted with Class II elastics, this distance is reduced and the intrusive force increases. This force will also increase by the power of four as the diameter

of the archwire increases. (Thornton and Nikolai 1981). Where class II elastics are worn, there is both a retractive force and an extrusive force. Class II elastics of approximately 60gms will reduce the intrusive force of an archwire by approximately 12 grams or 20%. The further distally the helices are placed on the archwire for elastic attachment the less is the extrusive force, thus where overbite correction by intrusion is desired, place the helices more distally along the arch wire (Xu *et al.*, 1992). Intrusion using single point brackets and round wire allows each individual tooth to seek a path of least resistance in intrusive displacement. The absence of torque pressure permits effective intrusion with very light forces (Burstone 1977, Thornton and Nikolai 1981).

As a guide for the clinician the anchor bend must be increased or the diameter of the wire raised as the antero-posterior distance in arch length increases. This is of greater significance when first permanent molars are removed and second permanent molars are used for anchorage (Xu *et al.*, 1994).

Anchorage bends mesial to the lower molar tube will elevate the lower molar as well as intrude the lower incisors. Where intrusion of incisors is desired with minimal molar elevation, anchorage curves will have less effect on molars and more intrusion of incisors in conjunction with class II elastics (Lew 1990).

Tip back bends provide strong downward and backward movement to the maxillary molars and a continuous intrusive force on the maxillary incisors.

As the incisors are intruded and the overbite is reduced there is the possible elimination of functional retrusion (Nasiopoulos *et al.*, 1992).

OVERJET

Overjet reduction has been traditionally carried out by retracting maxillary anterior teeth sometimes assisted by forward movement of lower anterior teeth to produce a class I canine relationship. Where there is a skeletal component in the overjet during active growth, functional appliances may be used to advance the mandible or extra oral traction used to restrain the maxilla.

Use of class II elastics to retract incisors should be combined with intrusive mechanics in the archwire. This will limit the extrusive potential of the elastics and also move the centre of rotation of the tooth further forwards the apex. (Ten Hoeve *et al.*, 1977). Force from such elastics needs to be kept as low as 50-60gms to allow tipping of the incisors as the crowns are retracted. The centre of rotation should be as close as possible to the apex of the tooth during tipping. With Class II elastics there is little change in the position of the maxillary molars as the incisors are retracted. (Hurd and Nikolai 1977).

ROTATIONS

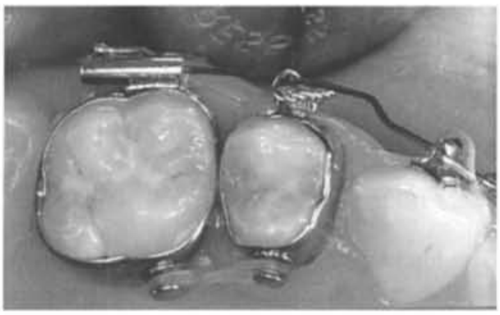
Rotations may be corrected simply by engaging the archwire into the bracket slot. The thicker the arch wire the more effective is the rotational correction. However, additional correction may be achieved in four ways. Firstly, with the arch wire offset bayonet bends may be placed to apply a differential pressure point in the opposite direction of the rotated tooth.

Secondly, the bracket may be offset on the tooth to provide an additional movement from the bracket to the wire or a sleeve may be placed under the margin of the bracket to push the tooth further away from the arch wire.

Thirdly, auxiliary rotating springs made of 0.014 wire may be fitted into the bracket (Fig. 5A). These are slid through the bracket from the gingiva and with the spring arm at right angles to the archwire, the end is bent off the bracket against the labial surface of the tooth. As the hook arm is engaged onto the wire, there is a rotational force applied to the crown in either a clockwise or anticlockwise direction.

Fourthly, elastic thread or chain may be threaded from a lingual attachment to the archwire or adjacent teeth to de rotate a tooth (Fig. 5B & C).

A



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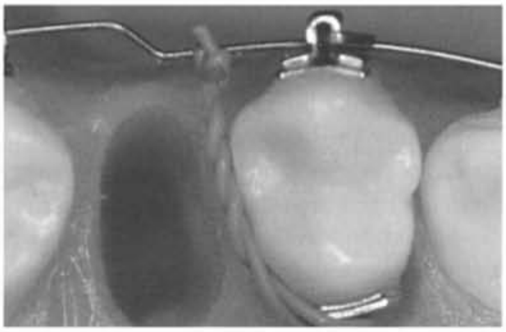


C

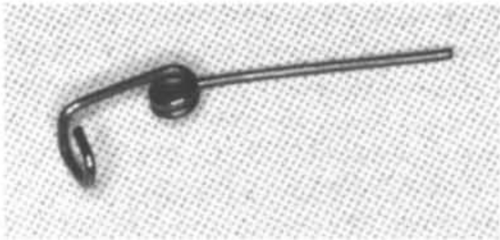
Fig. 5. A - Rotating spring: The vertical arm is inserted through the channel and with the hook at right angles to the tooth surface, bent over against the tooth. As the hook is engaged onto the archwire, the coil spring is activated.

B - Chain elastics placed onto lingual buttons will control rotated premolars.

All rotations should be treated as early as possible during active treatment and held in an overcorrected position until finishing wires are placed. Derotated teeth have a strong tendency to relapse and either require long retention and or pericisions to minimise this.

UPRIGHTING

Uprighting of teeth is carried out with auxiliary springs. The most effective are the 0.10" Wilcock supreme wire mini springs. These springs are inserted from the gingiva through the bracket slot under the arch wire. The hook is placed over the archwire to activate the spring either mesial or distal to the bracket (Fig. 6A, B, C & D).



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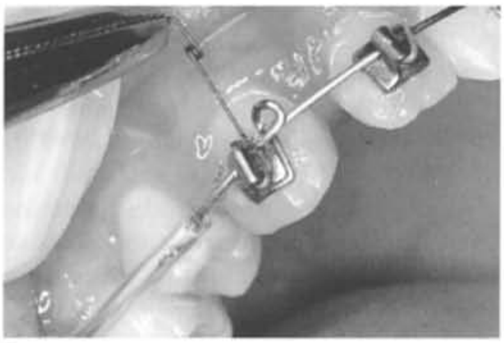

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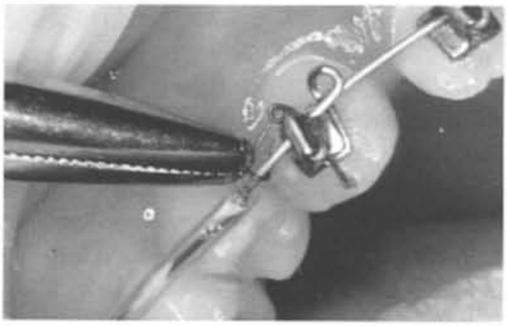

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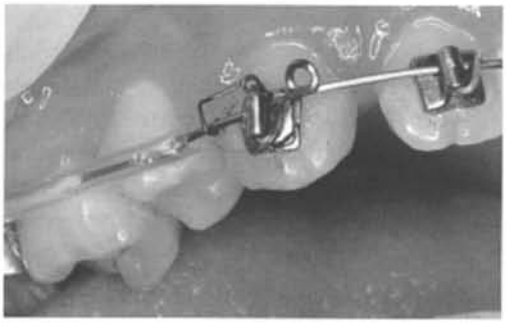


D

Fig. 6. A - 0.010" minispring (AJ Wilcock).

B - Insertion of minispring behind the main archwire.

C - The hook end is engaged onto the archwire activating the coil spring.

D - The end of spring is bent over the occlusal surface of the bracket to fasten.

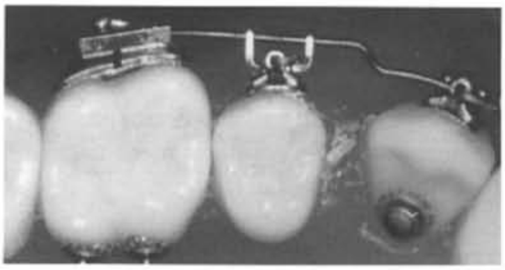
SPACE CLOSING (STAGE II)

In a severe crowding case or where the reduction of overjet and or levelling of the curve spee determine the need for extractions, such extraction spaces are usually not completely closed following the correction of the above factors. Where premolars have been removed the canines should first be set into a good Class I relationship and residual spaces closed by bringing the molars forward. Space closure is thus, by sliding mechanics once the overbite and overjet have been reduced, all rotations placed in an overcorrected position and the teeth in good alignment.

Frequently, the mechanics plan is to minimise the retraction of the anterior segments as the posterior segments are brought forward. Sliding mechanics with ribbon arch stainless steel brackets is a low friction appliance and will allow rapid movement of teeth (Kameda 1994).

Archwire diameter should be raised to a minimum 0.018" premium + to maintain arch coordination and overbite reduction. Where first premolars have been removed the archwire should be offset around the remaining premolar bracket and lightly engaged. Where possible the Kameda bypass loop is the attachment of choice as this stabilises derotations and limits tipping of the premolar into the extraction space (see chapter 9).

A



B

Fig. 7. A & B - By pass loop pins (Biodent - Yamaura, TP orthodontics).

BRAKES

To limit the retraction of the anterior segment particularly the lower incisors, a braking arch can be fitted to the incisors as a sectional auxiliary or "piggy back" arch wire. Ribbon wire of 19 x 22 or 20 x 20 can be slotted into the brackets from 33 to 43 and the main arch wire pinned over it.

The addition of uprighting springs to the canines will also restrict the distalisation of the canines although there is always some distal placement of the anteriors with closing mechanics.

Latex chain elastics hooked from the helix on each canine to the molar hook are placed in each quadrant. These elastics should be stretched prior to placing as this reduces the initial force to a consistent level. The elastics remain in the mouth and do not need changing for four weeks.

To control the molar positions the arch wire may require some toe in to offset the elastic pressure. Alternatively, power chain can be fitted lingually from the molar button to the archwire between the lateral and canine teeth. While 0.018" diameter wire may be adequate, 0.020" arch wire provides better molar control.

Should difficulty be anticipated in engaging the premolar brackets with the arch wire then a new arch wire of 0.014" diameter can be used for a brief period. This will even the heights of all teeth and coordinate the arches in preparation for torquing mechanics and finishing during Stage III.

TORQUE

Torque is the force that gives the operator control over the movements of the roots of the teeth (Rauch 1959). This force is in a circular motion in any of three planes of space (Mitchell and Kinder 1973). Torque is referred to by its effect and direction of action on the root. In most cases torque is directed to move the maxillary incisor roots palatally. Where roots are too far palatal as with instanding lateral incisors, labial root torque or "reverse torque"is indicated. Root torque may be carried out by means of torsion built into rectangular wires and engaged into the bracket. In these cases, the force magnitude is initially high and produces an interrupted force.

Alternatively, auxiliary wires are used "piggy backed"over the main arch to direct the roots (Fig. 8). These produce light continuous forces (Reitan 1985). Successful treatment is dependent on a satisfactory axial inclincation of the maxillary incisor. Significant palatal root torque reduces the tendency for overbites to relapse (Graber 1966).

Torquing maxillary incisor teeth requires considerable lower molar anchorage. Anticipation of such requirements is necessary prior to commencement of treatment. Incisally directed mouse trap torquing auxiliaries, delivers a more gentle force to the apices and can deliver different direction of torque to individual teeth using 0.011 Wilcock wire (Mollenhauer 1987).

Two spur- torque auxiliaries act as a lever against the labial tooth surface as the distal end of the auxiliary arch is tied to the main archwire (Scully 1972).

The degree of movement depends on the type of alveolar bone more than the duration of force applicaiton. Dense alveolar bone may cause a delay in the resorption process. Bundle bone is resorbed more readily than lamellar bone.

Forces between 100 gms and 200 gms result in hyalinisation and root resorption in the middle third of the root and apical third. Once started, this increases in the presence of strong continuous force.

Forces 50-70 gms produces only mild root resorption in the middle third and such superficial resorption is easily repaired. (Reitan 1985, Ten Hoeve and Mulie 1976).

Factors determining force magnitude:

- type of wire
- diameter of wire
- spur length
- spur angle
- diameter of auxiliary - as bent up
- axial inclination of teeth prior to torque
- intercanine width in maxilla

Type

Greater tensile strength (grades) of wire produce greater resilience and higher force values.

Diameter: Torque force produced is proportional to the fourth power of the wire diameter, e.g. 0.016"auxiliary produced forces slightly less than 0.014"(Scully 1972).

Lighter wires of 0.010 and 0.09"supreme grade wires (Wilcock) have been shown to produce ultra light forces with predictable torque. Use of rectangular shaped aligning auxiliaries produced bodily movement of incisors and reduces the amount of torque required at the finishing stage threby reducing anchorage requirements (Mollenhauer, 1989).

Forces produced by auxiliaries become progressively less as the roots move lingually. The intercanine width has an inverse realtionship with force values to individual teeth. As the tooth size decreases, forces increase. Therefore lighter wires or reduced activation is required in such cases (Neuger 1967).

Root resorption is unlikely to occur if tipping is contained with the trough of cancellous alveolar bone. (Kameda 1982). Mouse trap torquing with incisally directed boxes has the advantage of improved oral hygiene, particularly gingival hygiene. (Mollenhauer 1987). Gingivally directed torquing auxiliaries have the side effect of delivering extrusive forces to the anterior teeth. (Hocevar 1982). Incisally directed mousetraps will not extrude incisors and thus preserve the overbite correction.

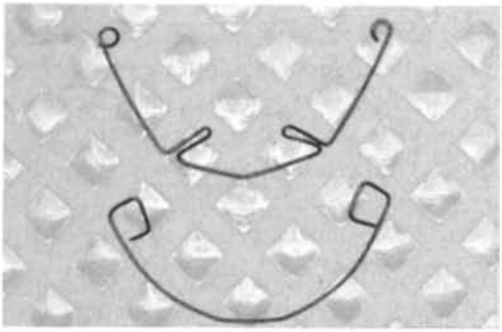
Expansion of the main archwire occurs as a side effect of incisor torquing procedures. Constriction of the main arch wire is an appropriate step to counteract this. (French 1989). Furthermore, buccall expansion has a gingivally directed component at the molar resulting in intrusion and tipping of the molar. (Foster 1968)

The amount of constriction employed as compensation should be proportional to the inclincation of the incisors to be torqued, i.e. the more retroclined the incisors the more constriction required (French 1989).

Excessive lingualisation of maxillary incisors will create a zone of hyalinisation in the area where the remaining dense cortical plate meets the lingual root surface. This hyalinisation acts as a fulcrum to the torque auxiliary and produces a forward and extrusive tooth crown movement. As this zone of hyalinisation re-organises there may be root resorption and a new area of hyalinisation develops. As this reaction repeats itself there will be a shearing of the incisor downward and forward along the dense cortical plate and root resorption results. There is no anatomical limit to tooth movement in the marginal area of the alveolar process. However there is a definite limit to tooth movement of the tooth apex against the palatal cortex.

After 12 months a well curved dense cortical plate will reappear and is associated with relapse of the previously attained torquing tooth movements. If the incisors are intruded into alveolar bone of the palate prior to retraction, the deleterious effects related

to the cortical plate will be minimised. Torque values at the apex are in the range of 0.12 - 0.189N. torque spurs of higher diameter (0016") or over, produce greater force levels (Hammond and Rock, 1991).



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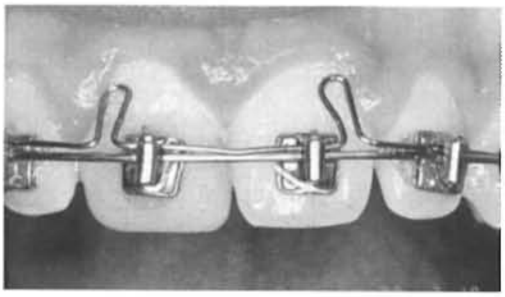


C

Fig. 8. A - Torque spurs (upper) and reverse torque (lower)

B - Reciprocal torque, torque to central incisors, reverse torque on lateral incisors

C - Torque central incisors only.

Modifications have recently been introduced to permit the use of ultra light forces with a low friction appliance to produce bodily movement during intial alignment (Mollenhauer 1989). This is particularly useful where the early control of lateral incisors from a cross bite position interupts intrusive mechanics and causes loss of anchorage. The use of aligning auxiliaries at the commencement of treatment allows both bodily movement and reciprocal torque, reducing the time towards the end of treatment in establishing the correct interincisal angles.

FINISHING ARCHES

Once root torque has been completed it is useful that the fixed appliances be left in place for at least 8 weeks (Reitan 1985). Replacement of active torquing auxliaries with finishing wires will cushion the problem of "tissue shock" (Mollenhauer 1987). Rectangular wires maybe used either in ribbon or edgewise form depending on the bracket to stabilise the torque and establish good buccal interdigitation. Alternatively, ribbon arches of .019"x .022" alpha titanium wires (AJ Wilcock) may be used in sections from canine to canine and along buccal segments as piggy back wires over the round stage III arch wires and pinned in securely with stage III pins (Fig. 9).

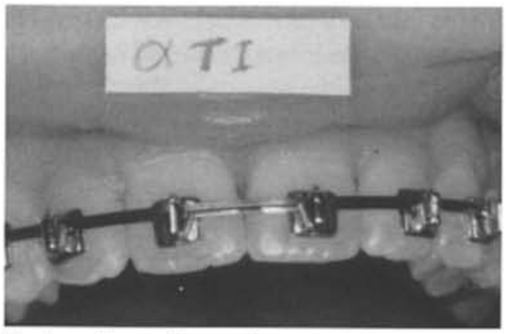


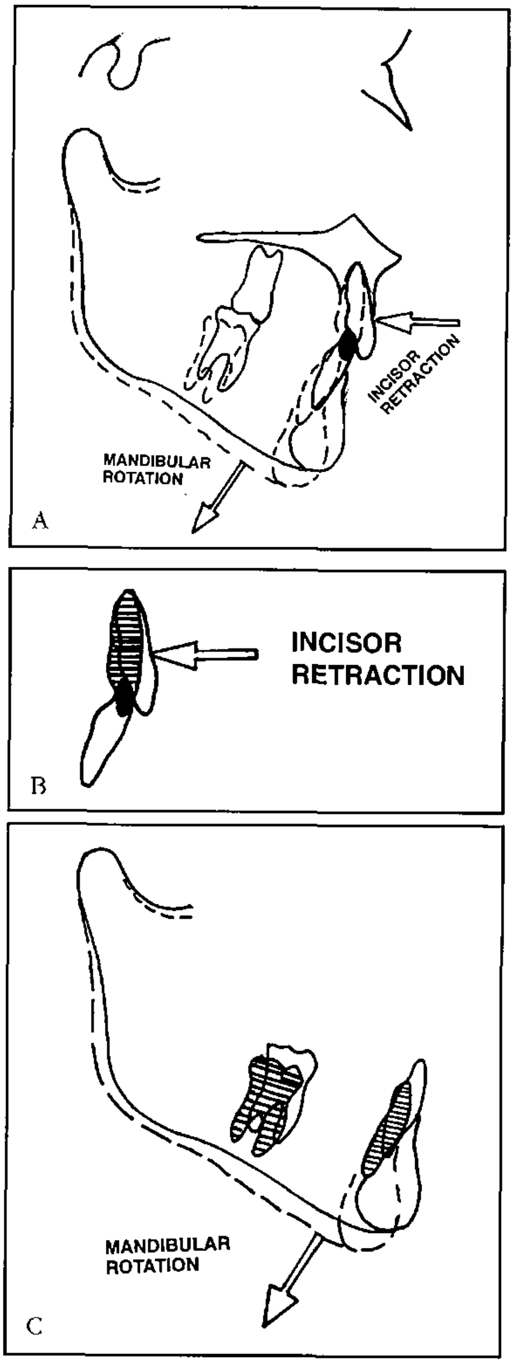
Fig. 9. α titanum ribbon arch over a stainless steel round wire as a fininishing wire.

TREATMENT OF CLASS II MALOCCLUSIONS WHERE THERE IS A DEEP BITE

Most class II division 1 malocclusions and almost all class II division 2 malocclusions have an associated deep bite. The Begg technique has always been known for its efficiency and effectiveness in rapid overbite *reduction simultaneously with rapid overjet* reduction. In any malocclusion where there is a deep bite, reduction of overbite must take priority over reduction of overjet or risk causing a mandibular rotation. (Jenner 1995) While this could occur with any orthodontic technique the risk is particularly high with the traditional Begg Lightwire appliance with its use of ribbon arch brackets, round wires and light class 2 elastics which provide such rapid retraction of upper incisors.

While the overbite could be considered a restriction limiting reduction of overjet, the efficiency of this appliance permits the upper incisors to retract creating an incisor "interference" which prevents full mandibular closure. A molar open bite is created as a consequence. However, molar eruption quickly closes the open bite as a consequence of the extrusive action of class II elastics. The molar open bite stage is rarely witnessed which explains why this process has gone unnoticed for many years. Thus, the consequence of premature incisor retraction is to create an incisor interference and mandibular rotation with molar eruption occurring as a consequence and not a cause of the mandibular rotation.

The phenomena of incisor interference and the associated mandibular rotation is illustrated in (Figs. 10A, B, C & D).



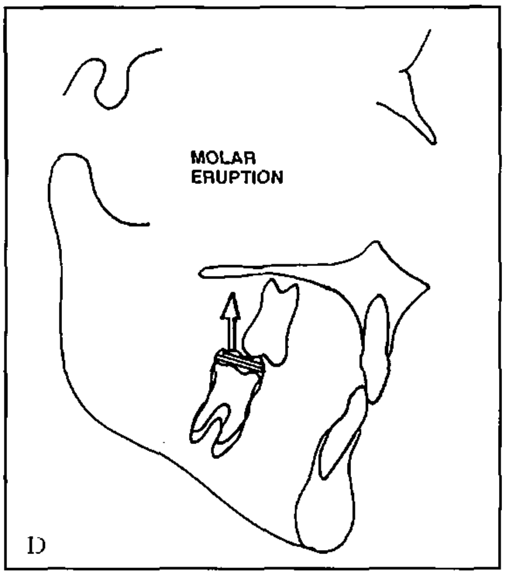


Fig. 10. A - Incisor interference is commonly caused by upper incisor retraction which prevents mandibular closure.

B - The upper incisor has been retracted into the space previously occupied by the lower incisor. The shaded area is the potential area of contact which is a measure of the incisor interference.

C - Mandibular rotation occurs as a consequence of upper incisor retraction and the creation of an incisor interference.

D - Molar eruption occurs because the mandibular rotation has left a posterior openbite. Lower molar eruption is more likely than upper molar eruption when Class II elastics are used.

The incisor interference risk can be easily assessed by examining the extent of overbite and the extent of overjet. With minimum overbite and maximum overjet the risk of upper incisor contact and interference is low (Fig. 11A). With maximum overbite and minimum overjet the risk of incisor contact and interference is high (Fig. 11B).

When incisor intrusion is minimal, rapid upper incisor retraction will create an immediate incisor contact which, in turn and almost without exception, leads to an instantaneous backward rotation of the mandible; a rotation that continues as long as upper incisor retraction continues, and ceases with the cessation of incisor contact.

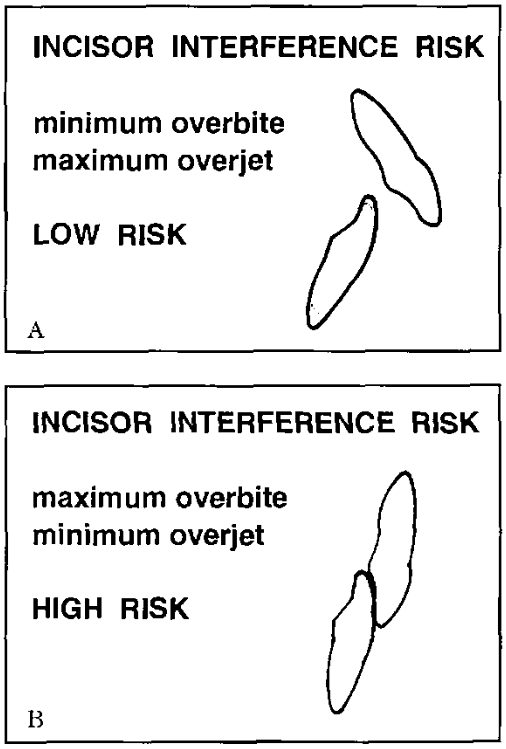


Fig. 11. A - A low risk of incisor interference exists with minimum overbite and maximum overjet. When the upper incisors retract there is a low risk that they will contact the lower incisors.

B - A high risk of incisor interference exists with maximum overbite and minimum overjet. When the upper incisors retract there is a high risk that they will contact the lower incisors.

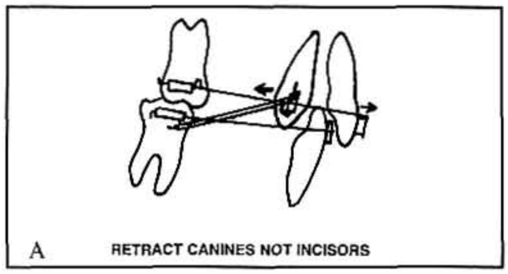
It should be noted that the danger of incisor interference and mandibular rotation is greatly increased by extraction of upper first premolars. In most non extraction treatments there is a more limited or restricted retraction of upper incisors with less incisor interference and less mandibular rotation.

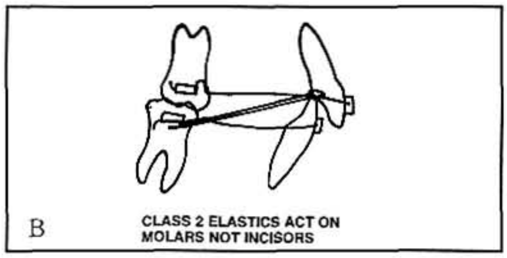
MINIMISING INCISOR INTERFERENCE AND MANDIBULAR ROTATION

To provide the best possible profile for patients with class II malocclusions, incisor interferences and mandibular rotations should be avoided by:

1. Using maximum anchorage bend function in an archwire able to transmit maximum upper incisor intrusion effect.
2. Commencing treatment without class II elastics. Wait until there is a clearance between the incisors before starting class II elastics.
3. Commencing treatment mechanics with elastics, provided they are the lightest elastics, attached to canine hooks rather than archwire hooks (Fig. 12A). In this way, incisor retraction is avoided during early treatment. Over powering of the upper arch wire with heavy class II elastics should be avoided: this will extrude the incisors causing incisor interference and downward and backward rotation of the mandible.
4. Using archwire stops against the molars will allow class II elastics to be used without initial incisor retraction and interference (Fig. 12B).
5. Using a posterior bite plate to reinforce molar anchorage and avoid incisor contacts while the bite is opened (Fig. 12C & D).

Incisor interference and mandibular rotation is illustrated with the superimposition tracings of two patients with class II malocclusions. In figure 13A, B, C and D, the effects of a gross incisor interference is illustrated. Note the considerable mandibular rotation. In figure 14A, B, C and D, note the good profile and minimal mandibular rotation associated with a minimal incisor interference.





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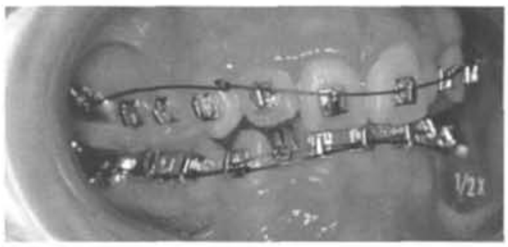


D

Fig. 12. A - Class II elastics can be used to retract upper canines rather than incisors by using super high hat pins in ribbon arch brackets and power pins in Tip-Edge brackets.

B - An upper molar stop maintains arch length and limits upper incisor retraction. Class II elastics worn to archwire hooks transfer activation to the molars.

C - A posterior bite plate.

D - With the posterior bite plate in place, bracket interferences are avoided and molar anchorage is reinforced.

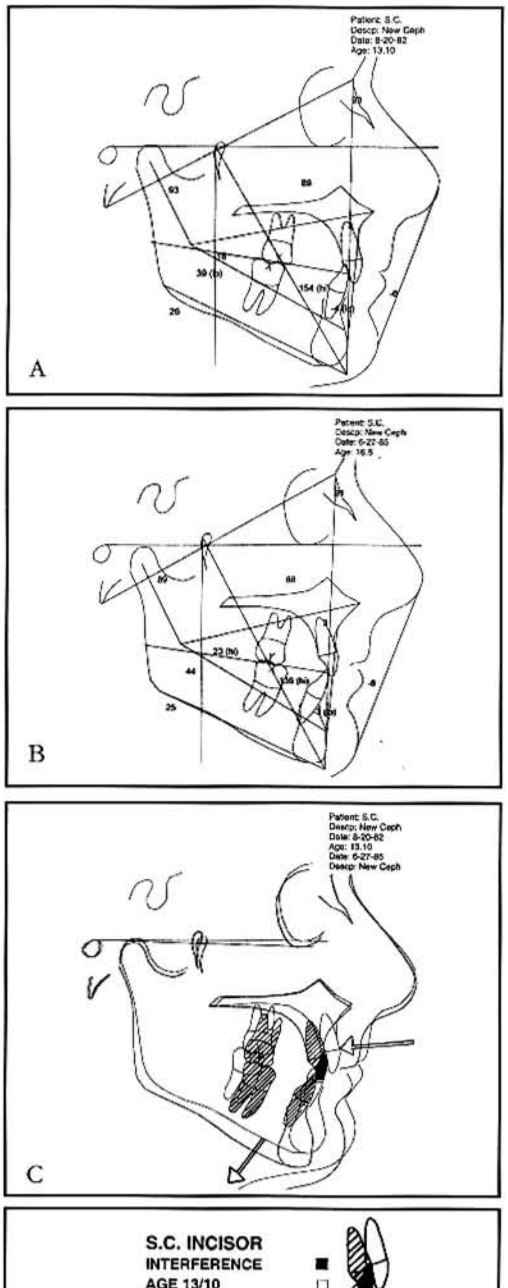


Fig. 13. A - SC Pretreatment tracing.

B - SC Post-treatment tracing.

C - SC Pretreatment and post-treatment tracings.

D - SC Incisor interference.

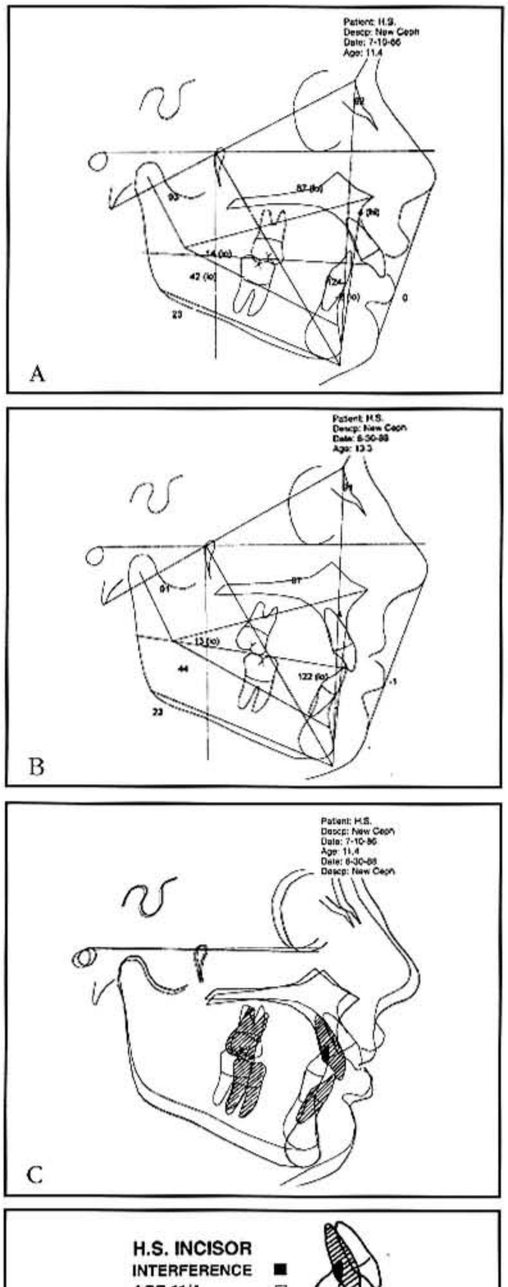


Fig. 14. A - HS Pretreatment tracing.

B - HS Post-treatment tracing.

C - HS Pretreatment and post-treatment tracings.

D - HS Incisor interference.

CLASS II CORRECTION IN AN ACTIVELY GROWING PATIENT.

In a non growing or adult patient the class II correction must proceed mainly by masking the underlying skeletal discrepancy. Usually, the removal of two upper premolars will permit the upper anterior segment to be retracted sufficiently to provide class 1 relations with the unchanged lower anterior segment. A major disadvantage of this mechanical form of class II correction is that the treatment goal is provided by the unchanged lower arch. At the end of treatment, in a situation of mandibular retrusion, the maxillary anterior teeth may appear over retracted, with consequential loss of preferred profile balance.

In an actively growing patient there is the opportunity to provide orthopaedic correction of the class II discrepancy. Where individual arches are uncrowded or only mildly crowded the orthopaedic correction can proceed without extractions. In a growing patient who requires extractions then there is a mixture of treatment mechanics employed. The retraction of the upper anterior segment can occur as for any non growing or adult patient. Superimposed on this is a restriction of forward development of the maxilla and maxillary teeth with continued growth of the mandible and mandibular teeth. As a consequence there is a mixture of dental and skeletal correction.

MECHANICS OF CLASS II CORRECTION

The orthopaedic effects of functional appliances are well known. Graber (1994) has listed the following likely contributions to a 6-7mm sagittal correction using a functional appliance.

1. Condylar growth amounts, 1.0 to 3.0mm (mandible outgrows maxilla to 1 to 5mm).
2. Fossa growth and adaptation, 0.5 to 1.0mm.
3. Eliminating functional retrusion, 0.5 to 1.5mm.
4. Providing a more favourable growth direction (trabecular angle), 0.5 to 1.0mm.
5. Withholding of downward and forward maxillary arch movement, 1.0 to 2.0mm.
6. Allowing differential upward and forward eruption of lower buccal segments, 1.5 to 2.5mm.
7. Headgear effect, 1.0 to 2.0mm.

Clinical and cephalometric evidence strongly supports the statement that if a patient is actively growing and class II elastics are being worn then there will almost certainly be an orthopaedic effect in class II management.

Each of these seven components of a class II correction are likely to occur in class II management with class II elastics. The varying amounts of each component will depend on growth increments, direction, timing and length of treatment. The case report KG is an example of favourable orthopaedic changes in class II correction using intra oral mechanics.

TREATMENT TIMING AND TREATMENT RESPONSE

Where the aim is to maximise orthopaedic change then the timing of treatment and assessment of the treatment response are very important.

1) Timing of treatment.

It is generally accepted that if orthopaedic change is desired in orthodontic treatment then it is wise to include the time of most rapid growth. The most effective orthopaedic change can be observed when treatment is carried out over an extended period of rapid growth.

It is possible to treat too early and find the patient is not growing and that the changes brought about by fixed appliances and class II elastics are predominantly orthodontic changes. The same can be said of treating too late.

2) Treatment response

The treatment response will vary from patient to patient. When the orthodontic records, examinations, analysis and all other criteria are considered, there is occasionally indecision about the best management of some class II patients. Commonly this will relate to a decision to extract or not to extract teeth. The final diagnosis should be based on the treatment response. In this way, the problem of diagnostic uncertainty is overcome in a positive way. To start treatment without extractions in order to test the treatment response is a valid diagnostic method. That is, provided always that the treatment response is continually evaluated and the decision reviewed. To complete a treatment non extraction because of indecision throughout treatment could be to accept an unstable treatment result at the end of the day.

Many treatments have been carried out over the years where extractions have been employed as a matter of habit in the manner of a cook book approach to class II treatment. The extractions have served to cover up the treatment response in corrections that could have been achieved without extractions. This applies particularly to the growing class II patient where an orthopaedic response should be expected.

ORTHOPAEDIC FRIENDLY MECHANICS TO BE EMPLOYED WITH FIXED APPLIANCES AND CLASS II ELASTICS

The following points have been found helpful in promoting orthopaedic correction with intra oral mechanics.

1. It will help in planning and implementation of treatment mechanics if it can be imagined that a fixed functional appliance is being inserted for each actively growing patient.
2. It follows that early reduction of overjet should be avoided as this will limit the extent of anterioposterior orthopaedic correction.
3. Priority should be given to reduction of overbite so that the mandible is free of incisal interference and is able to express the full potential of its growth in a forward rather than a downward and backward direction.
4. Avoid retracting upper incisors into contact with lower incisors and thus creating an incisor interference and mandibular rotation.
5. Use light or ultra light class II elastics 24 hours each day to provide continuous forces against the maxillary teeth and maxillary basal bone. The same elastics act on the mandibular teeth and the mandible.
6. A posterior bite plate is useful adjunct to support molar anchorage during deep bite correction. By minimising extrusion of molars there is an aid to vertical control thus maximising class II correction.

Orthopaedic friendly class II elastics with intra oral mechanics

Class II elastics provide the major method of class II correction. The way that the class II elastics are employed will determine if the changes are orthodontic or orthopaedic.

The class II elastics can be made orthopaedic friendly by:

1. Using the lightest possible elastics so that extrusive effects on the upper incisors and the lower molars can be minimised or avoided.
2. Attaching class II elastics so that they retract canines rather than incisors in initial treatment mechanics.
3. Alternatively if class II elastics are attached to hooks on the arch wire then employ molar offsets or stops to maintain arch length so that class II elastics will act on the upper molars and the maxilla and not retract the incisors.

ORTHODONTIC, ORTHOGNATHIC OR A COMPROMISED CLASS II CORRECTIONS?

A significant number of mature patients decline orthognathic surgery to correct their facial disharmony. Fortunately, a full class II occlusal correction can be successfully completed with fixed appliances and at least upper arch extractions.

It is very important that the patient and family understand the compromised circumstances of the treatment and provide their informed consent. However, it is a common experience, that in such patients the profile will deteriorate and in some, the facial appearance is unacceptable. In such circumstances there may be a place for partial correction of the class II malocclusion. This implies, that a preference is made in favour of maintaining an acceptable profile while providing a compromised occlusal correction. The buccal occlusion may be left in half unit class II or cusp to cusp occlusal relations while the incisor relation and canine relation will be compromised in a similar way. Where there is danger of deep bite recurrence this option is not advised.

There are many situations where the patient could elect to undergo long term retention. That is, the patient would accept full responsibility for the half treated malocclusion on the basis that it would always be unstable and relapse in part or total without ongoing retention. In such circumstances the compromised occlusion may provide the patient with acceptable facial aesthetics. There are situations of excessive overjet where the overbite is incomplete and there is no danger of palatal trauma. In such situations partial reduction of overjet may fulfil the aesthetic requirements without significant occlusal compromise.

Whatever the malocclusion, the option for extended retention may be usefully employed at the patients' option. The use of well placed and constantly monitored bonded lingual retainers provides an excellent basis for such extended retention.

MANAGEMENT OF MAXIMUM ANCHORAGE CLASS II MALOCCLUSIONS

Begg described three distinct treatment stages and established treatment objectives for each stage. The division of treatment into these same stages continue to be the most effective way to treat class II malocclusions requiring maximum anchorage conservation and control.

The stage objectives and methods are shown on the following page.

STAGE OBJECTIVES AND METHODS OF THE BEGG TECHNIQUE

Objective	How Achieved
Stage One	
1. Achieve an edge to edge anterior relationship by eliminating overbite, relaxing openbite and correcting cross-bites	A Upper and lower, .016" high tensile resilient wires. B Continual wearing of class 2 intermaxillary elastics.
2. Eliminate anterior crowding for desired rotational.	A Nickel titanium wires. B Plain arch wire plus anterior coaxial alignment auxiliary - when space exists distal to crowding.
3. Close anterior spaces with.	A Plain archwire with elastic force applied between cuspid brackets.
4. Overcorrect rotated cuspids and bicuspids.	A Rotating springs. B Elastomeric traction to the archwire or to an adjacent tooth.
5. Correct posterior crossbites.	A Modify posterior arch width of one or both archwires. B Wear bilateral cross bite elastics in conjunction with constricted and/or expanded archwires. C Rapid maxillary over expansion followed by a period of stabilisation prior to the placement of fixed appliances.
6. Overcorrect the mesiodistal relationship of the buccal segments.	A Continual wearing of Class II or Class III elastics. B Proper degree of bite opening bends in both the upper and lower archwires to eliminate incisal interferences.
Stage Two	
1. Maintain all corrections achieved during stage I.	A Upper and lower .20" archwires and intermaxillary elastics as required. B Elastomeric or steel ties from the cuspid brackets to cuspid hooks on the arch wire. C When possible, engage brackets of over rotated teeth on the archwire or hold rotations with steel ligatures. D Continual wear of buccal cross elastics and/or modification of archwire widths.
2. Close any remaining posterior spaces.	A Wear horizontal elastics, elastomeric chains or ligatures.
Stage Three	
1. Maintain corrections	A Space closure maintained by bending ends of archwire distal to molar tubes. B Refer to A,B,C, and D for stage two.
2. Achieve desired axial	A Axial inclinations of teeth are changed by the use of springs and/or maintained by the use of T-pins B Lingual (palatal) or labial root torque is achieved through torquing auxiliaries

MANAGEMENT OF MINIMUM ANCHORAGE CLASS II MALOCCLUSIONS.

In minimum anchorage cases, it is often helpful to introduce stage III auxiliaries in stage I and stage II. Begg recommended the use of incisor torquing auxiliaries at the commencement of stage II space closing. Thus, in the minimum anchorage case, at the end of stage II, the teeth would not be over retracted and appear retroclined. By the introduction of "braking" auxiliaries the anterior teeth are kept forward while class II correction and space closure takes place. This approach which may be termed a progressive stage III, requires constant monitoring of anchorage in relation to the treatment plan and treatment objectives.

An example of unnecessary over retraction of the anterior teeth is shown in Figs. 15A, B, C, D, E and F. While this case is an example of good recovery, an excessive amount of uprighting and root torque was required. In other circumstances this could have resulted in a retrusive profile more like the profile.

Figures 16A, B, C, D, E and F shows good use of anchorage control through the use of auxiliaries to prevent incisor over retraction while simultaneously carrying out stage III mechanics. Note the stage III auxiliaries in place with minimal retroclination of upper anterior teeth. In many situations it is possible to avoid the need for a separate stage III. This situation could be brought about by a progressive stage III approach or it could be that the treatment planning has permitted a greater orthopaedic component of the class 2 correction so that there is minimal retroclination of upper anterior teeth.

A

B

C

D

E

F

Fig. 15. A patient treated in 1984 with extraction of four premolars and exhibiting unecessary over retraction of the anterior teeth.

A - Pretreatment profile.

B - Pretreatment occlusions.

C - Mid treatment profile and retrusive lower face.

D - Mid treatment incisor relation with unecessary over retraction of anterior teeth.

E - Post treatment profile.

F - Post treatment incisor relation.

A

B

C

D

E

F

Fig. 16. A patient treated with extraction of four premolars and exhibiting good anchorage control to prevent the over retraction of the anterior teeth.

A - Pretreatment profile.

B - Pretreatment occlusions.

C - Mid treatment profile.

D - Mid treatment incisor relation.

E - Post treatment profile.

F - Post treatment occlusion.

RETENTION AND STABILITY OF CLASS II CORRECTIONS

Retention of the corrected class II malocclusion is just as important as retention following correction of other malocclusion types. Opinions will always vary over the extent and duration of retention just as opinions will always vary about the degree of responsibility of the operator over the long term stability.

To minimise relapse there is no better way than to treat to accepted standards of occlusion. In particular, after class II correction, the bucco-lingual relationships of all teeth should be fully corrected or slightly over corrected. The incisor relation should be corrected so that upper and lower incisors provide a favourable inter incisal angulation. The lower incisors, in particular, should not be excessively proclined and should be well supported by alveolar bone.

Care should be taken to treat to the retruded contact position and not a more forward bite of convenience. It is important to look for premature contacts and slides before removal of appliances. Relapse of occlusal relations and the incisor relation may not be relapse but an undetected discrepancy between centric relation and centric occlusion.

Stability of class II correction is most difficult to achieve in those patients who exhibit excessive vertical facial dimensions particularly during active growth. Many of these patients are predisposed to mandibular rotations as a result of cuspal interferences, weak musculature and mouth breathing. Such mandibular rotations will lead to vertical changes which may alter the occlusal relations in the class II direction. Prevention is better than attempting to provide a cure. Thus awareness of the possibility of cuspal interferences, particularly the minimisation of extrusive mechanics and where possible the use of the lightest elastics will mostly avoid such problems.

Begg advocated over correction of occlusal relations and the incisal relation. He did not intend that the over corrections remain but that they could facilitate 'settling in' to the ideal relationships of the teeth. In treatment with slight antero-posterior over corrections will minimise relapse of occlusal and incisor relations.

CASE REPORT (Fig. 17A, B, C & D)

Patient: NB *Age:* 12 years 4 months *Sex:* Female *Treatment duration:* 22 months

Appliances used: Begg ribbon arch

Chief complaint: Irregular upper incisor, deep bite with occasional pain.

Diagnosis: Skeletal base class II division II with mild mandibular retrusion.

Dental pattern class II division II with full unit class II occlusion.

Overbite 110%.

Agenesis 25. Immature, unerupted 15.

Treatment plan: Surgical removal of 15 and extraction of the 65.

Had the 25 been present, a non extraction start would have been the choice to test the response to class II correction. Peak growth velocity was expected in 6 months. The skeletal age was 11 years this being some 14 months late.

Treatment: Begg ribbon arch appliances with a posterior bite plate used to assist molar anchorage and archwire intrusive effect. Steel arch wires of 0.018 (A J Wilcock) with maximum anchorage bend function. The lightest class II elastics were started immediately.

Bite plate stopped after 5 months and upper intra arch space closing elastics commenced.

After 10 months root uprighting springs added to the 14, 13, 23 & 24 as brakes while space closing continued.

After 14 months 0.020 arches placed and a root torquing auxiliary added to the 11 & 21. This was 0.020 diameter steel and it was used for 6 months.

After 20 months finishing was commenced.

Retention: Removable upper and lower retainers. The upper molar teeth were slightly buccal and a circumferential upper retainer was used to push the molar teeth more palatal in post treatment finishing.

Cephalometric Changes: Considerable forward mandibular growth combined with considerable upper incisor palatal root torque.

Post treatment evaluation suggests that upper incisor retraction could have been less.

PRE-TREATMENT PHOTOGRAPHS

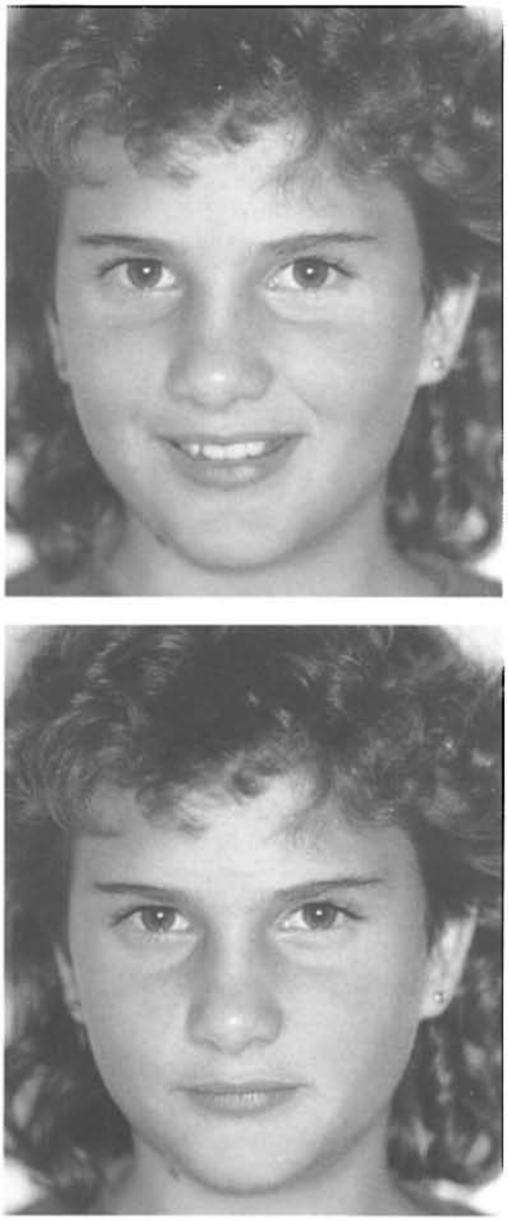


Fig.17. A - Pre treatment extra oral, intra oral and occlusal films.

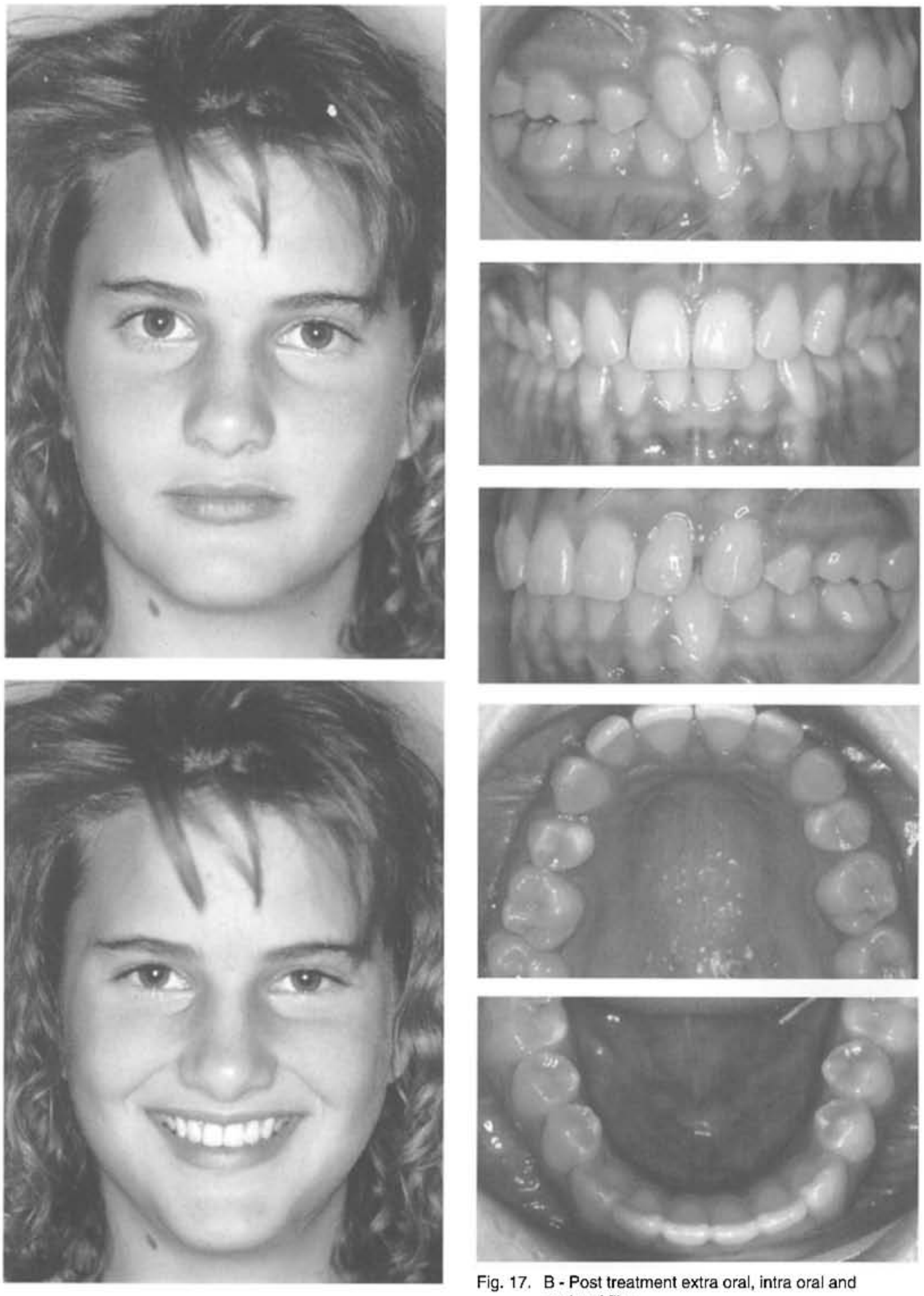


Fig. 17. B - Post treatment extra oral, intra oral and occlusal film.

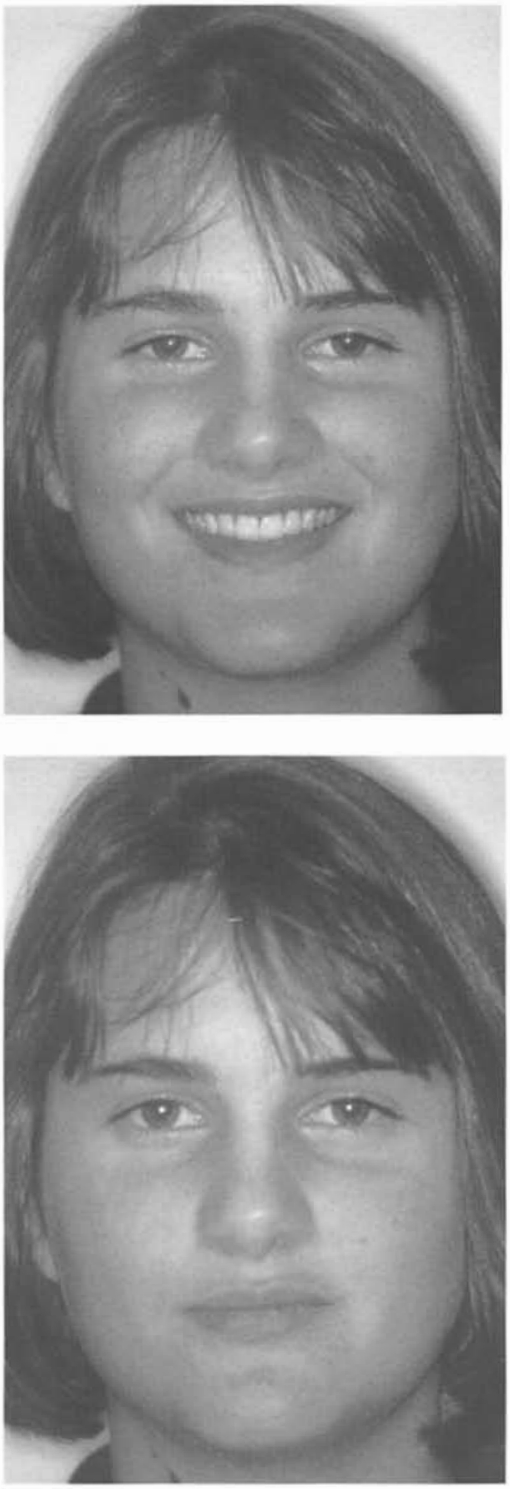
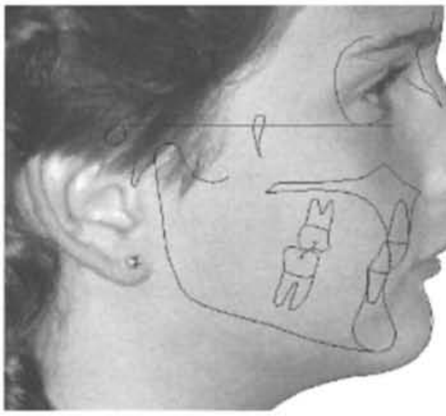
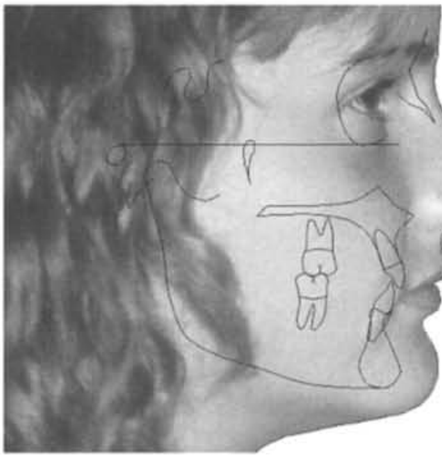


Fig. 17. C - 4 years after removal of appliances.





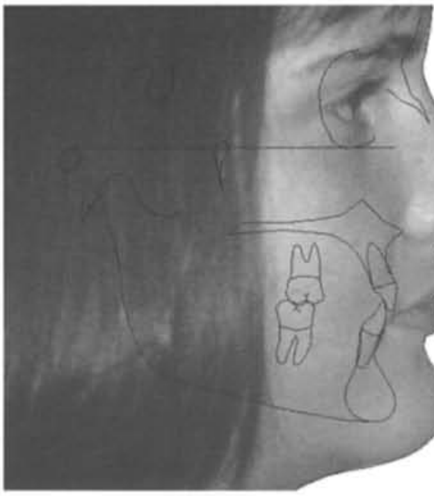


Fig. 17. D - Pre-treatment, beginning retention 4 years after bands off.

CASE REPORT (Fig. 18A, B, C, D, E & F)

Patient: HS

Age: 11 years 6 months

Sex: Female

Treatment Duration: 21 months

Appliances Used: Begg ribbon arch appliances

Chief Complaint: Very self conscious of upper incisor protrusion.

Diagnosis: Skeletal base class II. Maxilla slightly forward, mandible relatively retrusive. Slightly narrow face.

Dental relations full unit class II.

Lip protrusion and incompetence upper incisor protrusion. Over jet 12mm.

Traumatic deep bite.

Treatment Plan: HS was prepubertal with a skeletal age of 10 years and 3 months. The delayed development of 15 months provided the opportunity to treat during active growth.

Start without extractions and test the treatment response. Maximise orthopaedic restraint of maxillary growth. Improve vertical control and anchorage support using a posterior bite plate with initial treatment mechanics.

Should the treatment response be inadequate for full class II correction then removal of two upper premolars would be required.

Treatment: A full bonded Begg ribbon arch appliance was placed. Initial archwires consisted of 0.018 steel (A J Wilcock) with maximum anchorage bend function. The lightest class II elastics (5/8 light) were commenced immediately. A posterior bite plate was fitted.

Class II occlusal corrections progressed steadily with reduction of overjet occurring at the same time. Lip protrusion was reduced. Palatal root torque was applied to the 11 &21 for 4 months and reciprocal torque to the 12, 11, 21 & 22 for 3 months.

Retention: Both arches were retained with removable retainers for 2 years.

Cephalometric Changes: Early treatment mechanics caused some mandibular rotation. The class II correction was brought about by restrained maxillary growth, extensive mandibular growth, slight distal movement of upper incisors and mesial movement of lower molars.

PRE-TREATMENT PHOTOGRAPHS

Fig. 18. A - Pre treatment facial, intra oral and occlusal views.

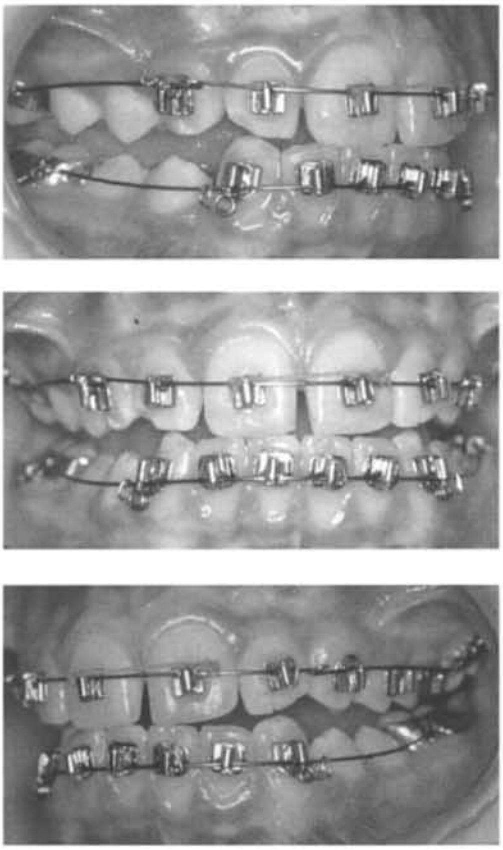


Fig. 18. B - After 10 months of treatment. Note the posterior open bite as the bite plate is stopped. The edge to edge incisor relation is now recognised as unhelpful because of the mandibular rotation it promotes. Torque added to 11 & 21, uprighting auxiliaries removed from 33 & 34 and added to 13 & 23 so as to restore a preferred incisor relation. Note that the upper arch wire has stops against the 16 & 26 molar tubes. This ensures that the full effect of the class 2 elastics is received by the 16 & 26 prior to the incisors. In this way maximum orthopaedic correction is possible.

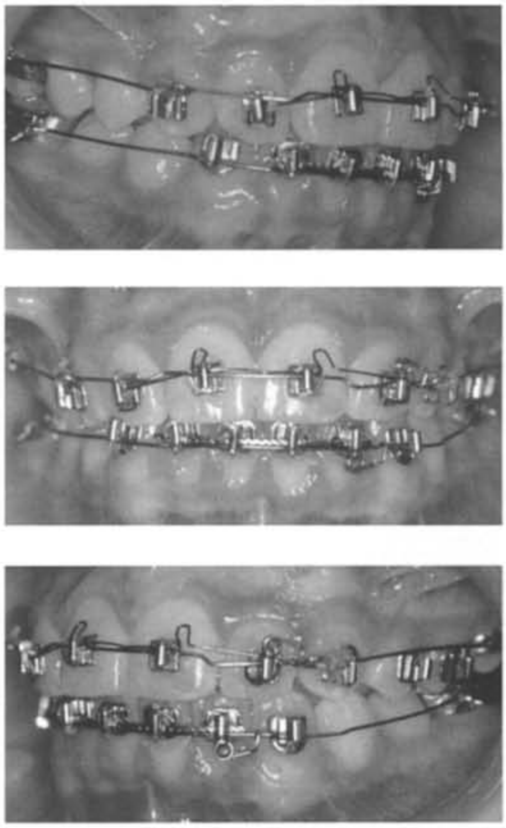


Fig. 18. C - After 19 months of treatment and near the end of stage 3. Note the reciprocal torquing auxiliary applying reverse torque to the 12 & 22, torque to the 11 & 21. The lower anteriors have a rectangular braking arch for control of crowns and apices.

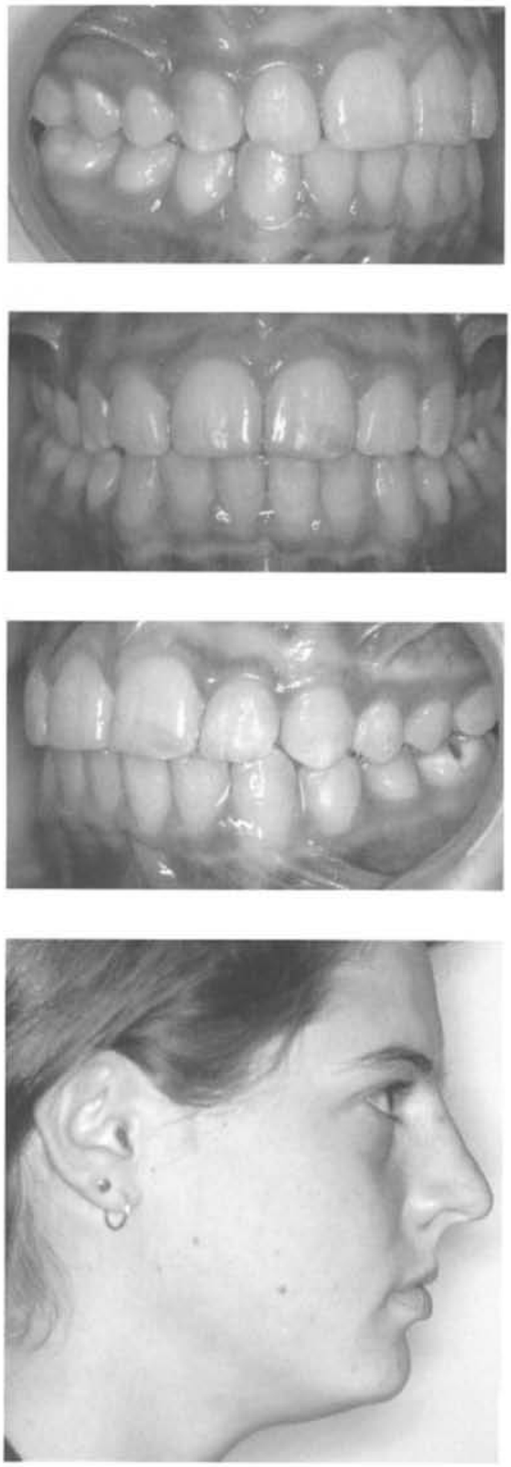


Fig. 18. D - End of treatment records. Note improved lip and facial balance and the full unit class 2 occlusal correction. The 17 and 27 are just erupting.






Fig. 18. E - Four years post treatment. Note well balanced profile and lip relations. While only 2 years out of retention there is evidence of stability.

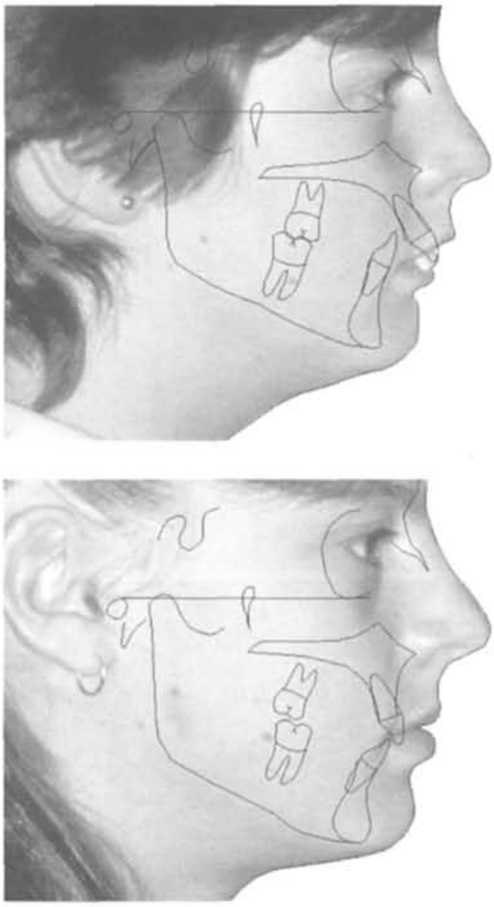


Fig. 18. Comparative Changes

F - Profile series showing dramatic changes between pre treatment, completion of treatment and four years later.

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18
Treatment of Class III Malocclusions

Doyle Baldridge

DIAGNOSIS OF A CLASS III MALOCCLUSION

Dr. Edward H. Angle (1907) defined a Class III malocclusion as one in which the mandibular arch was mesial in its relationship to the maxillary arch. There was a division of those cases that were unilaterally Class III into a subdivision in the right or left quadrant. Angle's system was based on what he considered a fixed relationship of the permanent maxillary first molar to the cranium. His classification of malocclusions established a procedure of grouping all like cases and a criteria for differentiating between groups of unlike cases. Angle's objective was to group together cases having similar characteristics to facilitate the study of both aetiology and treatment of malocclusions. His classification was a great step forward in diagnosis, but he gave no directions to quantify irregularities and the magnitude of a specific malocclusion. A first step toward determining the details of a malocclusion grouped into Class III is to study the characteristics of a specific case. All malocclusions grouped into the Class III category will have one or more of the following characteristics:

Hard tissue characteristics:

- Mandibular apical base measures 2mm or more anterior to the maxillary apical base (-2 WITS). Maxillary anterior teeth lingual to the mandibular anterior teeth.
- Anterior open bite.
- Maxillary anterior teeth in a deep lingual relationship to the mandibular teeth. Maxillary arch narrow and tapering.
- Maxillary lateral incisors instanding in relation to central incisors and cuspids.
- Mandibular arch larger, longer and wider than the maxillary arch. One or more mandibular posterior teeth in buccal crossbite.
- High mandibular plane angle.

Soft tissues characteristics:

- Maxillary lip thin and retrusive.
- Mandibular lip thick and protrusive.
- Tongue posture at rest generally within the mandibular arch.

The second step in diagnosis and treatment planning of a Class III malocclusion is the determination of the magnitude of the linear discrepancy between the arches. The Dual Plane Cephalometric Analysis, developed by

(Cannon, 1986). supplies valuable information to define the magnitude of a Class III malocclusion. This analysis determines normality of the cranial base length relative to the age, sex, and nationality of the patient. It assesses the spacial relationship of the maxillary/mandibular complex with the total face, and it depicts the anterior-posterior relationship between point A, Pogonion, and Nasion. Collectively, the information specifically defines the direction and amount of movement the orthodontist must accomplish to correct all Class III malocclusions.

THE BEGG APPLIANCE

Dr. P.R. Begg developed a new philosophy and technique of orthodontic treatment. His approach to the treatment of severe apical base discrepancy malocclusions was unique in that it provided a method to adequately compensate for these discrepancies. His technique made possible the movement of tooth relationships into proper positions of function and esthetics without resorting to difficult and dangerous surgery.

The selection of the Begg Appliance is recommended to treat cases that have severe linear discrepancies between the apical bases of the maxillary and mandibular arches. The ribbon arch bracket combined with resilient wires provides an ideal combination of materials from which a Begg orthodontic appliance can be constructed to treat all Class III malocclusions without utilization of surgery. The ribbon arch bracket is the essential element of an orthodontic appliance that functions as the archwire source dictates. Such an appliance is **wire** driven and promotes freedom of tooth movement through an unlimited distance. Unrestricted, controlled, rapid tooth movement is necessary in order to treat a severe class III malocclusion within a reasonable time frame.

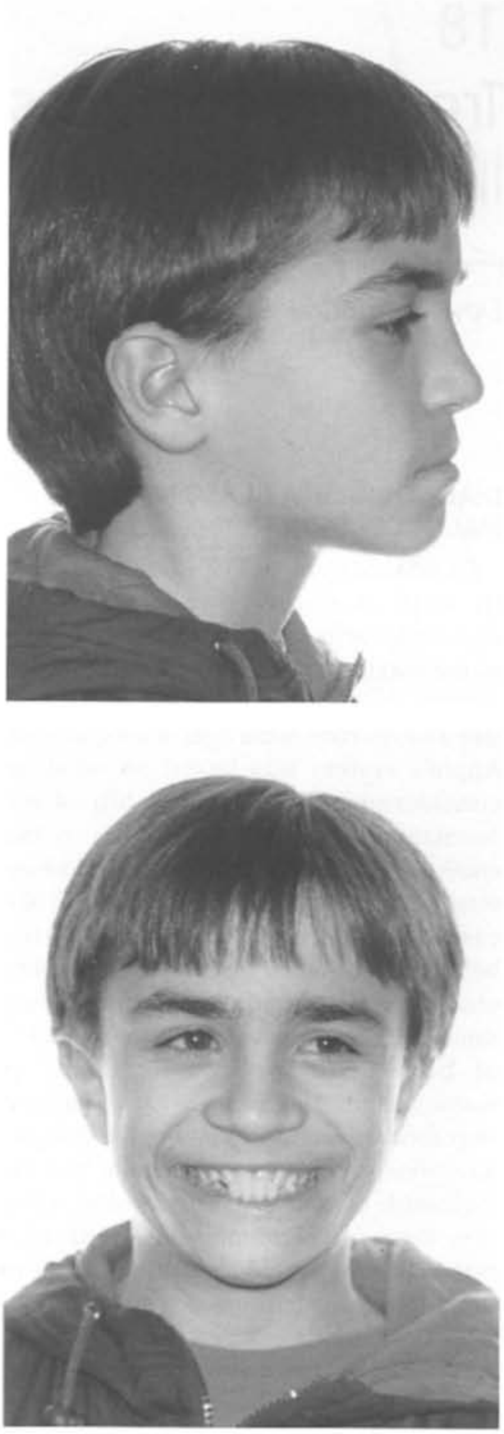
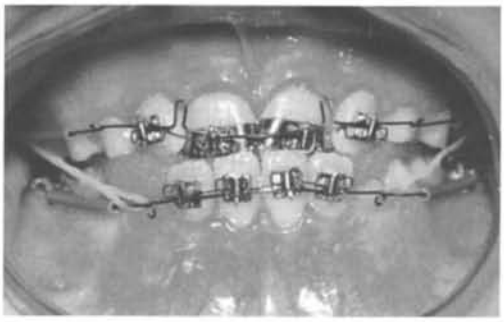


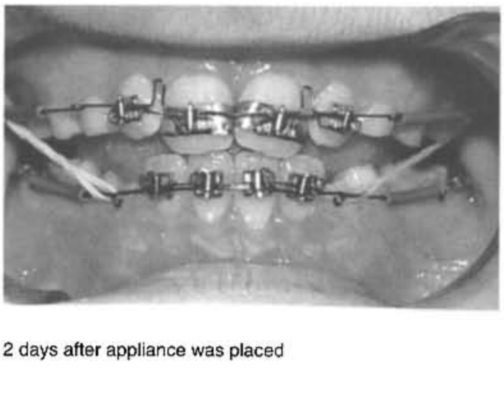
Fig. 1. Initial extraoral photographs of case B. L., age 11.

Rapid physiological tooth movement **can** be accomplished through first tipping, then uprighting the crowns and roots with use of resilient, hard archwires of small diameter, passing loosely through ribbon arch brackets attached to all anterior teeth and extending through .036 inch round tubes attached to first or second molar bands (Fig. 1 and 2).

Anterior crossbite



Day of appliance placement



2 days after appliance was placed

6 days after appliance was placed

3 mos. after appliance was placed

Fig. 2. An appliance that fulfils requirements for rapid tooth movement.

The following considerations must be given to the placement and use of ribbon arch brackets, archwires and buccal tubes in the fabrication of the Begg appliance for treatment of a class III malocclusion. The mandibular buccal tubes must be positioned sufficiently inferior to the maxillary buccal cusps of the opposing anchorage teeth to prevent bending or distortion of the mandibular archwire during function.

Cases having a narrow, tapering maxillary arch and anterior open bite require buccal tubes to be positioned so line up wires passed through the buccal tubes will project five millimetres inferior to the maxillary incisor teeth. Cases with a deep maxillary overbite would require the maxillary buccal

tubes positioned so line up wires would pass incisors at their gingival margins. During the first and second stages of treatment, molars and bicuspids are controlled by properly forming the archwires passively in the horizontal plane. When bicuspids are banded, the arch wires may be stepped out 2mm mesial to the bicuspid brackets in an amount equal to the width of these brackets (Fig.3,A). The anchorage bend should be placed in the usual manner.

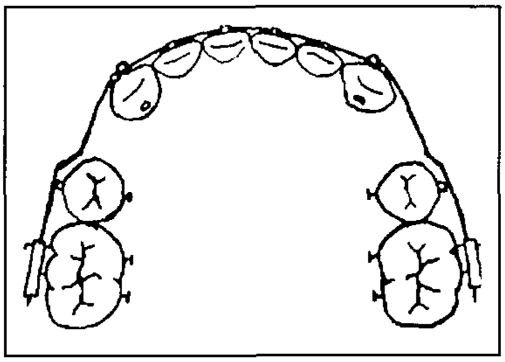


Fig. 3. A - Bicuspids banded.

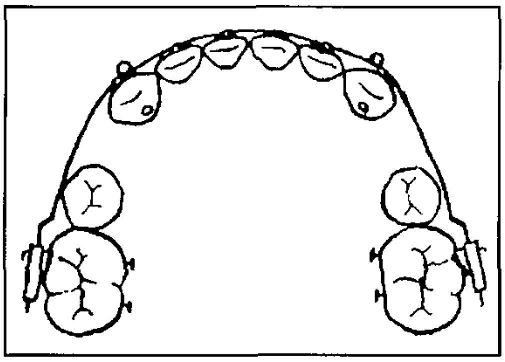


Fig. 3. B - Bicuspids not banded.

When archwires are placed and bicuspids are not banded, the step out bend can be placed just mesial to the anchorage bend (Fig.3,B). This will enable the archwires to pass vertically through the buccal tubes.

Reasons for placing step out bends in the buccal segments of the archwires:

1. Improves molar control.
2. Ease of archwire adjustment enables wire to pass through the buccal tubes vertically.
3. Quickly establishes and maintains good arch form.
4 Avoids taking bicuspids on a round trip lingually between first and third stages.
5. Avoids rolling mesio-buccal cusps of first molars lingually.

AN EFFECTIVE METHOD OF MOLAR CONTROL

Through the use of oval buccal tubes and doubled-back .016, .018 or .020 inch archwire, *problem molars* and *perverted molars* both may be controlled.

1. *Problem molars* are those which have roots that are too weak or those where there is not enough juxtapositional tooth support to provide anchorage stability.
   A. Molars which must be used for anchorage but where the tooth just mesial to it is congenitally missing or has been extracted presents a definite problem in molar control.
   B. Occasionally second and third molars present roots with cross sectional areas which are too small to allow control of the crown with a single wire.
   C. A doubled-back wire greatly increases anchorage preservation; more so than a single wire when used on "critical" anchorage cases.
2. *Perverted molars* are those which are linguo-verted, bucco-verted, tipped mesially or distally.

A. Construction of the doubled-back portion of the archwire in the opposite direction of the tooth perversion will correct molar position and promote a proper occlusal relationship.

B. Form proper crown torque into the doubled-back wire during fabrication because adjustment of the doubled-back wire in a bucco-lingual or linguo-buccal direction after construction is very difficult.

C. The horizontal loop mesial to the cuspid bracket plays a definite roll in the positional relationship of the doubled-back portion of the archwire.

ELASTICS

Gentle elastic stimulation is used consistently to move teeth and alveolar bone to complete correction of all linear arch discrepancies. Extremely light stimulation is applied to the lower anterior segment of teeth by intermaxillary elastics (approximately one and one-half ounce) worn *consistently*. Class III elastics are utilized until all mandibular teeth have been retracted sufficiently to produce a definite Class II, division 1 relationship between maxillary and mandibular anterior teeth (Fig. 4). A general rule to apply in over treatment at this stage is that the greater the negative Wits number in millimeters before treatment, the greater should be the magnitude of overtreatment. It is absolutely necessary to overtreat this type malocclusion to achieve an effective result and retain it throughout the patient's life.

Fig. 4. Overtreatment of the Class III malocclusion to a Class 11 division I relationship between maxillary and mandibular teeth is necessary at the end of stage 1. Inter and/or intra elastic force is utilized as needed.

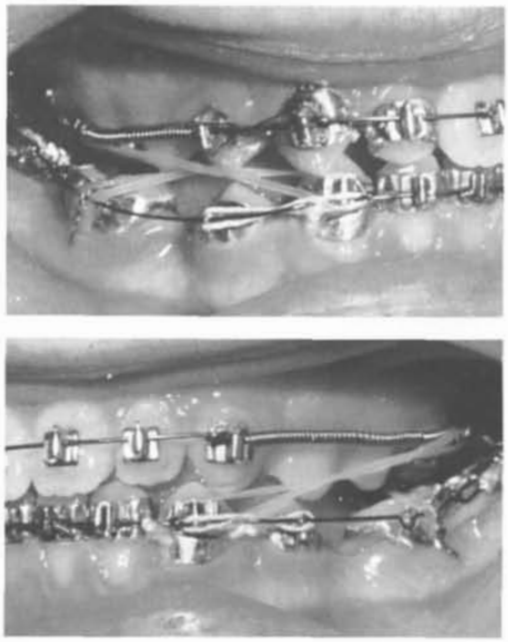


Fig.5. A and B - Maxillary molars in crossbite.

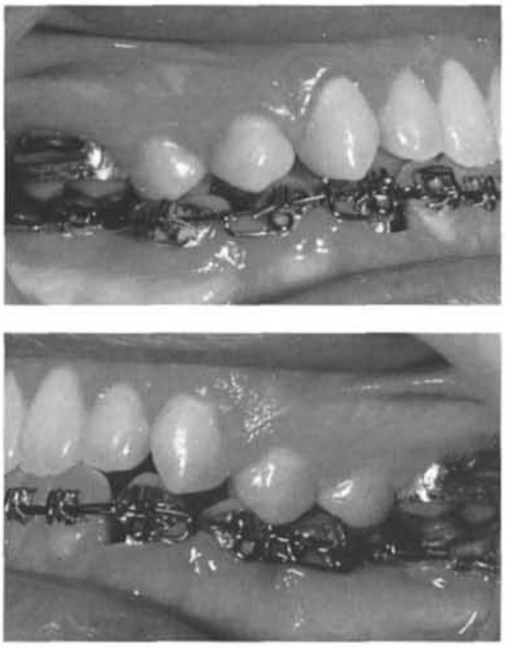


Fig. 5. C and D - Overtreated posterior crossbite.

During treatment, careful attention must be directed to consolidating spaces as all roots are aligned within the channel of alveolar bone. An overbite of anterior teeth should be established to produce ideal incisal guidance. Treatment of severe linear discrepancy cases demands that maxillary first molars be over expanded one or two millimeters, bilaterally, beyond the ideal occlusal relationship (Fig. 5, A through D). The expanded maxillary molars are held in a slightly buccoverted position throughout treatment.

ROOT TORQUE AND UPRIGHTING

At this point in treatment, oval buccal tubes should be installed on first molar teeth to complete and hold proper buccal root torque. The lingual cusps of maxillary molars must not engage mandibular molars prematurely. A premature engagement of these cusps will interfere with proper incisal guidance and cuspid rise. Parafunction during treatment as well as in post treatment has been attributed to premature maxillary lingual cusp contact during function with the mandibular molar teeth.[8]

Upon completion of Stage II, auxiliary wires are fabricated into torquing arches and uprighting springs which are installed onto archwires that have been coordinated and modified to fit passively into all brackets. Both archwires and auxiliaries are tied and/or pinned into all ribbon arch brackets. Many forms of torquing arches have been utilized to torque the roots of teeth. All are effective but all have their advantages and disadvantages of which the orthodontist must be aware.

The most popular torquing arch is one fabricated from Wilcock .014 inch premium wire. One to six spurs, approximately 3mm in length, are formed within the concave curve of the wire. Each spur should lie distal to the juxtapositional ribbon arch bracket. The distal end of the auxiliary may terminate at any point distal to the cuspid brackets or may extend on through the end of the buccal tubes.

The main archwire should be constructed from Wilcock premium grade wire of .018 or .020 inch diameter and must be passive in its contact with each bracket and both end tubes to prevent flaring of the molars through reciprocal forces produced by the torquing auxiliaries. Oval buccal tubes on anchor teeth are best for use by an orthodontist that has limited experience with the Begg appliance. Positive lingual crown torque must be formed into the mandibular doubled-back archwire. Buccal root torque is required in the maxillary doubled-back archwire.

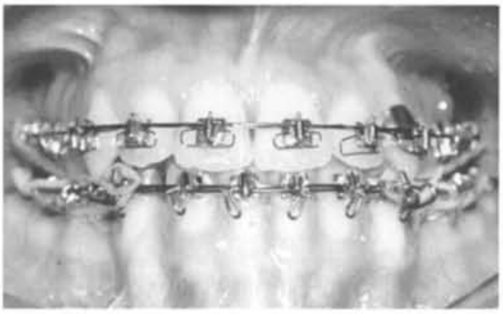


Fig. 6. Torque applied to all mandibular anterior teeth.

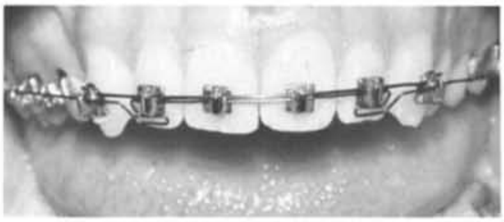


Fig. 7. Labial root torque applied to lateral incisors. Torque is applied to each root selectively.

The mandibular incisor roots are torqued lingually through use of an auxiliary with two or more spurs. These spurs engage the roots of anterior teeth on the labio-gingival third of the crown underneath the ribbon arch brackets (Fig.6). Alveolar bone will remodel if torque is kept within physiological force limits and the resulting stimulation is applied over a long period of time (nine to twelve months). Lingual alveolar bone is monitored by feeling the surface lingual to the incisor roots. Any root found to be too prominent should be relieved of further force from its torquing spur.

The maxillary lateral incisor roots require labial root torque in most instances while the central incisor roots seldom need torque (Fig. 7). The lateral incisor roots should be **gently** torqued through stimulation provided by a two spur torquing arch. The spurs should be at 45° to the horizontal and press lingually on the labio-incisal third of the lateral incisors crowns. Stimulation applied by this auxiliary to lateral incisors must be **physiological** in order that alveolar bone will still surround the labial surface of the roots after movement has been completed. Proper lateral root movement will require eight or nine months of torque if lateral roots were instanding before treatment was begun. Never, should a greater force be used over a shorter period of time.

.010 MINI-SPRINGS

The most efficient and reliable uprighting springs are .010 inch mini-springs (Squires, 1993). The .010 inch mini-spring incorporates significant design features which differentiate it from previous root tipping springs. These include the very small coil size (inner diameter of approx. 0.7mm), incorporation of 0.25mm (.010 inch) diameter 'Supreme' grade wire and a spring leg, arising tangentially from the uprighting coil.

FACTORS CENTRAL TO MINI-SPRING PERFORMANCE

A.J. Wilcock's stainless steel wire belongs to the ferrous group of alloys in general. And the American Iron and Steel Institute (AISI) 300 series of austenitic stainless steels in particular. The binary iron/chronium system is the foundation of the stainless steels, with differences arising from variations in composition, microstructure and crystallographic factors.

Unique thermo-mechanical processes are employed by A.J. Wilcock's Scientific and Engineering and Equipment which maximise a wire's dislocation densities. This is variously described as 'Pulse straightening' (Dynamic-Strain Ageing) to create wires that demonstrate high resilience values and hence high energy per unit volume. It also demonstrates zero stress relaxation maintaining its 'punch' over periods of six to nine months.

Pulse straightened wire takes advantage of the Bauschinger Effect. By avoiding reverse straining, A.J. Wilcock's wire, particularly the higher grades, approaches, for all practical purposes, the upper limits of performance that may be expected from austenitic stainless steel wire. By contrast, spinner straightening produces wire of low energy per unit volume with properties not consistant with the well accepted orthodontic goal of light, continuous force or periodontal stimulation.

Shorter uprighting spring lever arms, are superior to the longer uprighting spring arms in as much as they are of equivalent efficiency through larger, more resilient coils, are self retaining, as in the well known uprighting spring pin design and do not interfere with adjacent uprighting spring lever arms.

Begg and Kesling (1977) prescribed uprighting springs with wire diameters of 0.014 inch, 0.016 inch and 0.018 inch to upright, respectively, the mandibular incisors, premolars and canine teeth. Loading values of six, fourteen and twenty-four ounces were given.

With regard to orthodontic springs, conformational variables include helix diameter, number of turns in the helix, and cantilever arm length.

An orthodontic spring should also be loaded in the direction the spring is wound to take advantage of the Bauschinger effect. They concluded by stating that the principle of light, continuous force (stimulation) delivery is dependent primarily upon the structural design of the appliance and secondarily on the mechanical properties of the wire.

The mini-spring design eliminates a sharp bend at the coil to stem junction. This, together with the use of very high tensile 'Supreme' grade wire, has resulted in a reduction of the physical size of the mini-spring, increased energy storage capacity and increased elastic deflections.

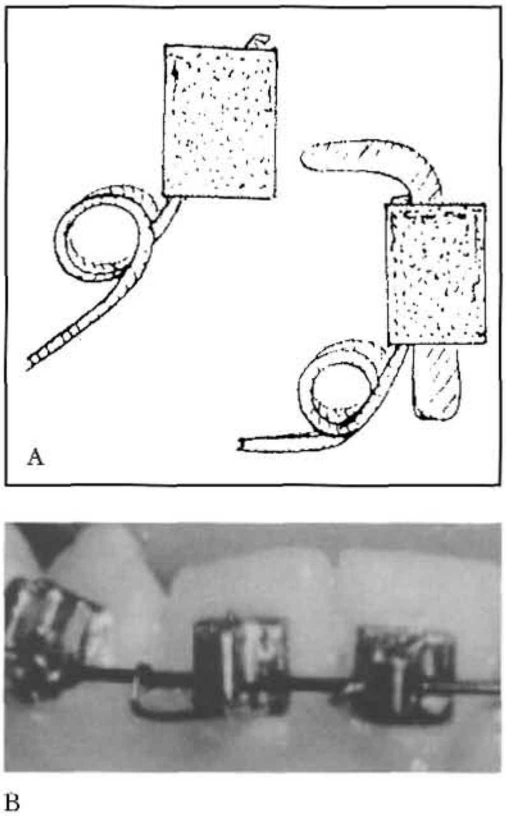


Fig. 8. A - Mini-spring placement. Keep coil spring away from entrance to vertical slot of bracket.

B - .010 miniature spring correctly placed into bracket.

NEW APPROACHES TO THE BEGG APPLIANCE

Advantages and benefits provided to both patients and the orthodontist are tremendous. A few of these advantages are listed below: (Mollenhauer 1987)

A. First and third stages of treatment may be combined and completed within the first six to nine months of treatment.

B. Much treatment time is saved.

C. The patient's maxillary anterior teeth align quickly and look nice throughout treatment.

D. Instanding lateral incisors are corrected physiologically. Treatment is accomplished through use of Mollenhauer Anterior Aligning Auxiliaries (MAA's) which are fabricated from Supreme grade Wilcock wire, (Fig. 9, A & B), that when properly activated, can accomplish physiological crown and root positioning within the first six to nine months of treatment (Fig. 10). This auxiliary facilitates rapid anterior tooth movements over a great distance within a relatively short period of time.

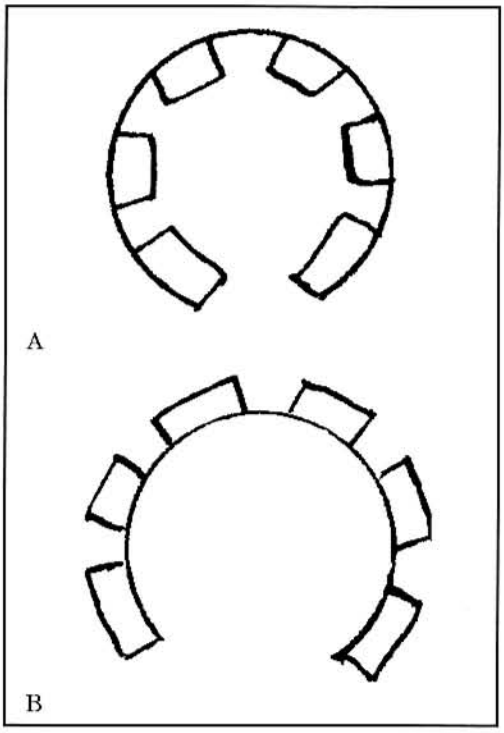


Fig.9. Mollenhauer Anterior Aligning Auxiliary (MAA)

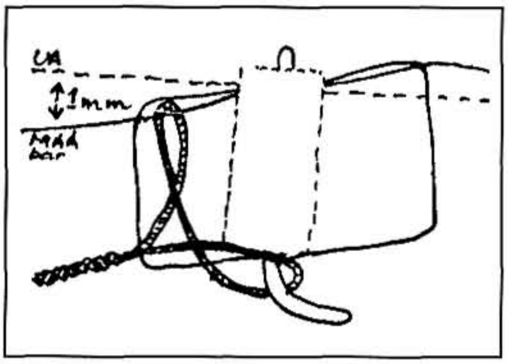
A - The above wire form constructed from .009 Wilcock supreme grade wire produces labial root torque on all maxillary incisors within the first six to nine months of treatment.

B - The above wire form constructed from .009 Wilcock supreme grade wire produces lingual root torque on all mandibular incisors.

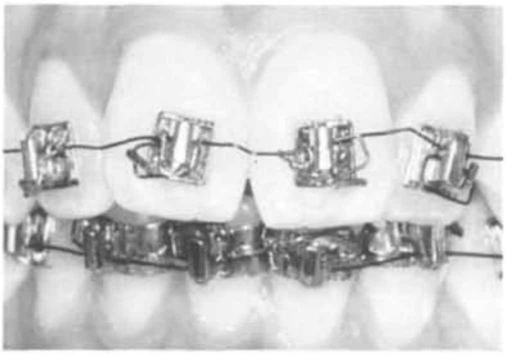
Fig.10. MAA showing completed labial root torque on maxillary lateral incisors.

Fig. 11. .010 inch miniature springs inserted into brackets on lateral incisors.

Midlines can be corrected as roots are uprighted through use of .010 inch minisprings inserted into ribbon arch brackets[1] (Fig. 11), An efficient technique to upright roots and correct midlines can be accomplished by tying a .010 inch ligature wire around the MAA bar and tail of the hook pin. This arrangement is called an MAA tip[1] (Fig. 12,A & B).



A



B

Fig. 12. A - Diagram of MAA tip.

B - MAA tips installed, roots move in direction of pin tail.

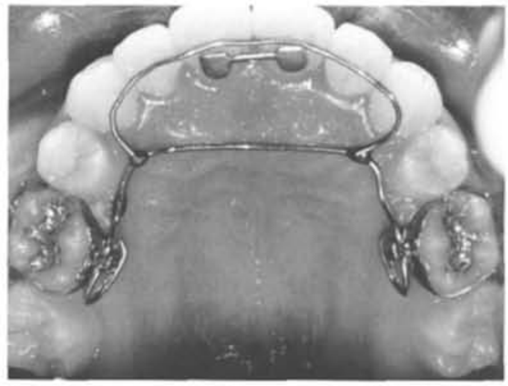


Fig. 13. Upper arch is retained by use of a lingual arch placed on maxillary molars.

Fig. 14. Upper incisors bonded on the lingual surface with fiberthread.

Fig. 15. Lower cuspid to cuspid retainer with hooks for Class III elastic wear.

RETENTION OF CLASS III MALOCCLUSIONS AFTER CORRECTION

Often orthodontic treatment is completed on the maxillary arch several months before uprighting and torque is finished among the teeth in the mandibular arch. When treatment of the upper arch has been completed, it is retained by use of a lingual arch maintaining the expanded position of the maxillary molars and engaging the lingual surfaces of the maxillary incisors, cuspids and first bicuspids (Fig, 13). Cases having torsiverted incisors and/or cuspids before treatment are retained through bonding these teeth on the lingual surface with fiberthread (Fig. 14) or metal pads connected with a bar (Fig. 13).

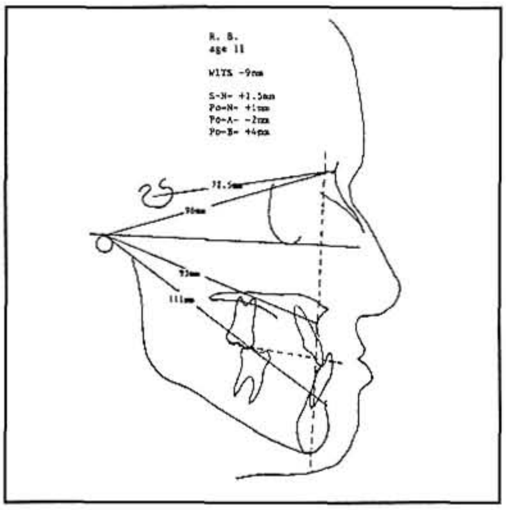
Retention of the mandibular arch after treating a severe linear arch discrepancy is insured by placing bands on the mandibular cuspids with attachments on the labial surface for use in Class III elastic wear when necessary (Fig. 15). This type of retainer is constructed using wire .036 inch in diameter to connect the cuspids on their lingual surface.

Case study:

R.B. Female, Age II years.

Clinical evaluation: Angle Class III, mandibular protrusion. All maxillary teeth were in lingual crossbite with the mandibular teeth. This case has all characteristics outlined as occurring in Class III malocclusions with the **exception** of an anterior open bite (page 1).

APPLYING THE DUAL PLANE ANALYSIS TO A CLASS III MALOCCLUSION



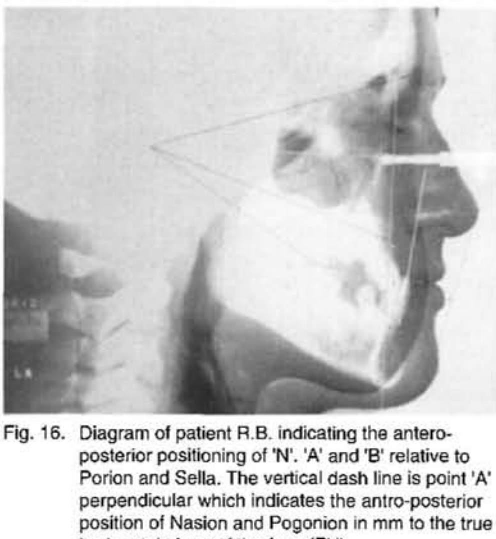


Fig. 16. Diagram of patient R.B. indicating the antero-posterior positioning of 'N'. 'A' and 'B' relative to Porion and Sella. The vertical dash line is point 'A' perpendicular which indicates the antro-posterior position of Nasion and Pogonion in mm to the true horizontal plane of the face (FH).

Frankfort Horizontal has been accepted as the true horizontal of the face.[1] Therefore, Point 'A' Perpendicular tells us that case R.B.'s Nasion is 6mm anterior and Pogonion is 5mm anterior to the maxillary base. The conclusion is that the maxillary alveolar bone is recessive. The skeletal pattern of the face is thus concave in the area of the mid-face leaving the lower lip protrusive. The E-Plane demonstrates this picture graphically.

The Wits measured -9mm. Nasion appears in good position antero-posteriorly to both Porion and Sella. The distance of Porion to 'A' point was 2mm less than standard for an 11 year old female, indicating a recessive maxilla. Porion to 'B' point (+4mm) indicated a longer than normal mandible. The mandibular central incisors were 5mm anterior to the AP line and the maxillary incisors were 3mm posterior to the AP line, Mandibular teeth and/or alveolar bone must be retracted 6mm, while maxillary teeth and/ or alveolar bone must be moved anteriorly 4mm to establish normal incisal guidance. One half of the total 10mm of tooth movement (5mm) is needed to compensate for R.B.'s apical base discrepancy.

TREATMENT PLAN

The Visual Treatment Objective to achieve lip balance and ideal functional occlusion required movement of the maxilla and/or maxillary teeth anteriorly 4mm. The mandibular alveolar bone and/or anterior teeth must be moved posteriorly 6mm. The Net movement required of alveolar bone and/or teeth is 5mm. Extraction of all first bicuspids was indicated.

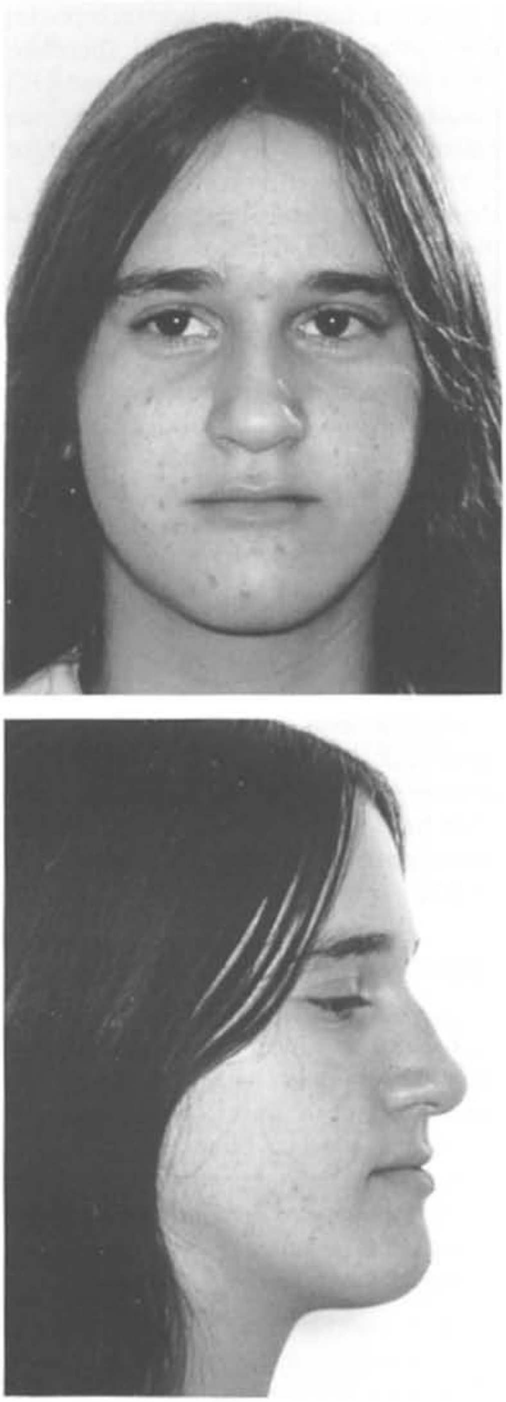


Fig. 17. R.B. Age II years. Beginning photographs.

Fig. 18. R.B. Age 11 years. Beginning intraoral photographs.

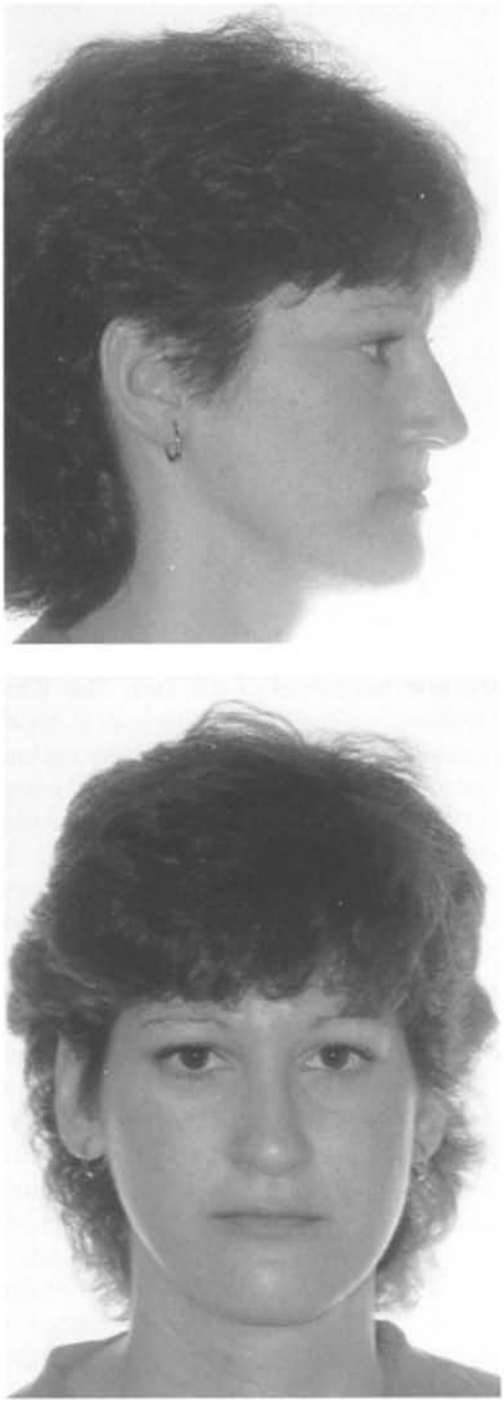


Fig. 19. R.B. Age 27 years. 14 years post finished photograph.

Fig. 20. R. B. Age 27 years. 14 years post finished intraoral photograph.

Fig. 21. Post finish cephalometric analysis of patient R.B.

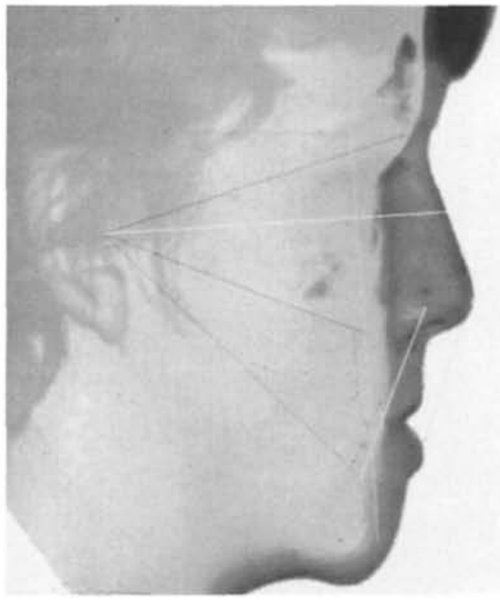
Case study:

C.B. Male, Age 15 years.

Clinical evaluation-. Angle Class III, mandibular protrusion, steep mandibular plane angle, mandibular second bicuspids were congenitally missing and there was an anterior open bite. This case has all characteristics outlined as occurring in Class III malocclusions with the EXCEPTION of a deep anterior overbite.

APPLYING THE DUAL PLANE ANALYSIS TO A CLASS III MALOCCLUSION

Fig. 22. Diagram of patient C.B. indicating the antero-posterior positioning of 'N', 'A' and 'B' relative to Porion and Sella. The vertical dash line is point 'A' perpendicular which indicates the antero-posterior position of Nasion and Pogonion in mm's to the true horizontal plane of the face (FH).



Frankfort horizontal has been accepted as the true horizontal of the face. The Wits measured - 15mm. Nasion appears in good position antero-posteriorly to both Porion and Sella. The distance of Porion to 'A' point is 17mm less than standard for a 15 year old male and Porion to 'B' point is normal. A perpendicular line through 'A' point defines the position of Nasion (+15mm) and Pogonion (-1mm) antero-posteriorly to the maxillary base. The mandible's length and position was normal, but the maxilla was moderately recessive. The mandibular central incisors were 5mm anterior to the AP line and the maxillary incisors were 4mm posterior to the AP line. Mandibular teeth and/or alveolar bone must be retracted 6mm, while maxillary teeth and/or alveloar bone must be moved anteriorly 5mm to establish normal incisal guidance. One half of the total 11mm of tooth movement (5.5mm) is needed to compensate for C.B.'s apical base discrepancy.

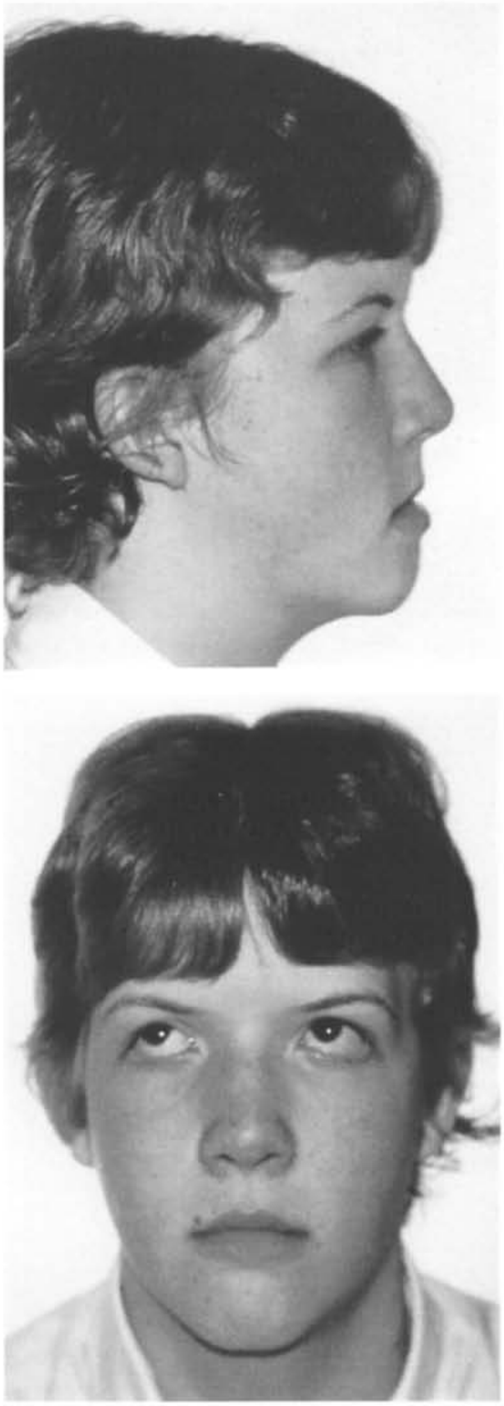


Fig. 23. C.B. Age 15 years. Beginning photographs.

Fig. 24. C.B. Age 15 years. Beginning intraoral photographs.

Fig. 25. C.B, Age 17 years. Finished intraoral photographs.

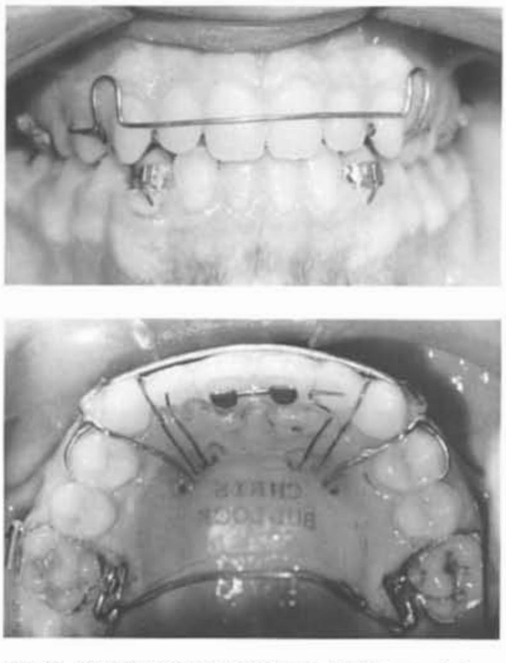


Fig. 26. C.B. Retention, age 17 years. Maxillary centrals bonded, transpalatal arch and buccal tubes for elastic wear if necessary. Mandibular cuspid to cuspid retainer with labial hooks for Class III elastic wear if necessary.

Fig. 27. C.B. Age 21 years. 3 1/2 years post treatment extraoral photographs.

Fig. 28. C.B. Age 21 years. 3 1/2 years post treatment intraoral photographs.

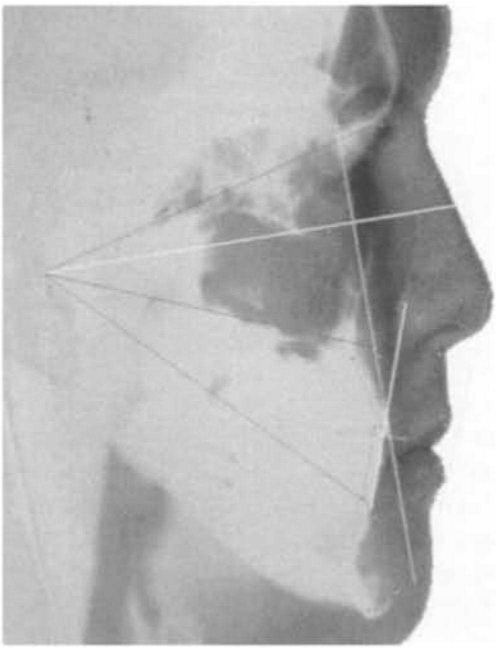


Fig. 29. Post finish cephalometric analysis of patient C.B.

Case study

T. J. B. Male, Age 11 years.

Clinical evaluation: Angle Class III, mandibular protrusion, maxillary lateral incisors and central incisors were excessively instanding, the anterior bite was deep, the right second bicuspid and right first molar were in lingual crossbite. This malocclusion has all characteristics outlined as occurring in Class III cases with the **exception** of an anterior open bite.

APPLYING THE DUAL PLANE ANALYSIS TO A CLASS III MALOCCLUSION

Frankfort Horizontal has been accepted as the true horizontal of the face. Therefore, point. 'A' perpendicular tells us that case T. J. B.'s Nasion is 6mm anterior and Pogonion is 2mm posterior to the maxillary base. The conclusion is that the maxilla lies in a normal position.

The Wits measured -9mm. Sella to Nasion measures +2mm, Porion to Nasion measures +4mm indicating a long cranial base. Porion-Pt. 'A' is normal length. Porion-Pt. 'B' measured +7mm indicating an excessive mandibular length in relation to the upper face. The mandibular central incisors were 4mm anterior to the AP line and the maxillary incisors were on the AP line. Mandibular teeth and/or alveolar bone must be retracted 5mm, while maxillary teeth and/or alveolar bone must be moved anteriorly 1mm to establish normal incisal guidance. One half of the total 6mm of tooth movement (3mm) is needed to compensate for T.J.B.'s apical base discrepancy.

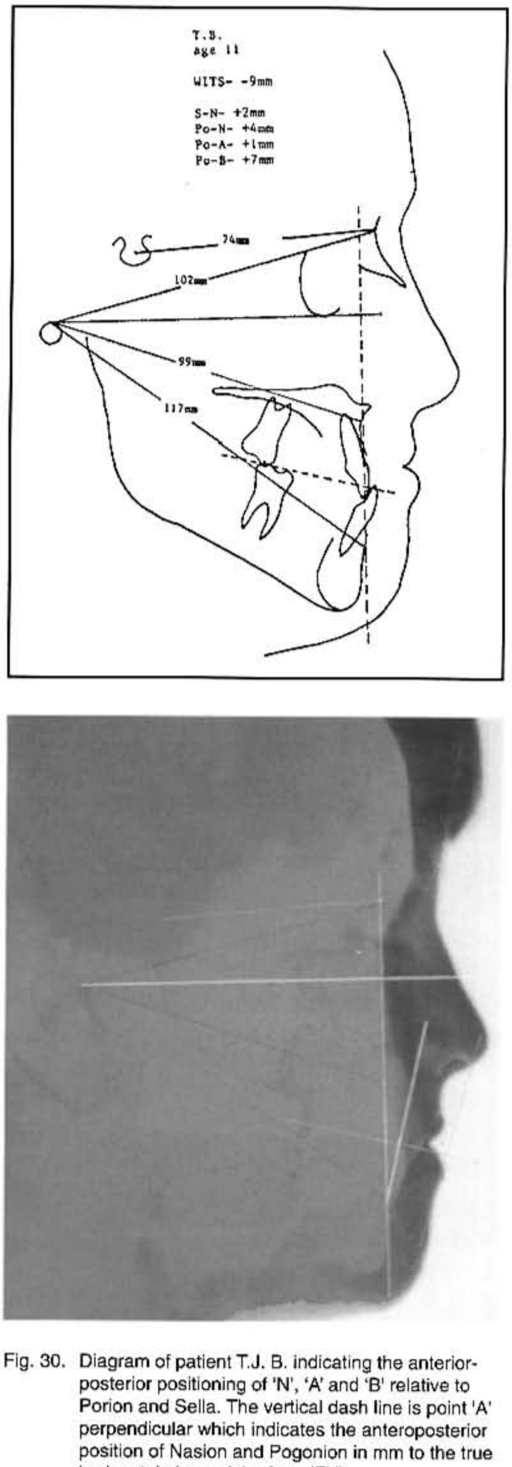


Fig. 30. Diagram of patient T.J. B. indicating the anterior-posterior positioning of 'N', 'A' and 'B' relative to Porion and Sella. The vertical dash line is point 'A' perpendicular which indicates the anteroposterior position of Nasion and Pogonion in mm to the true horizontal plane of the face (FH).

TREATMENT PLAN

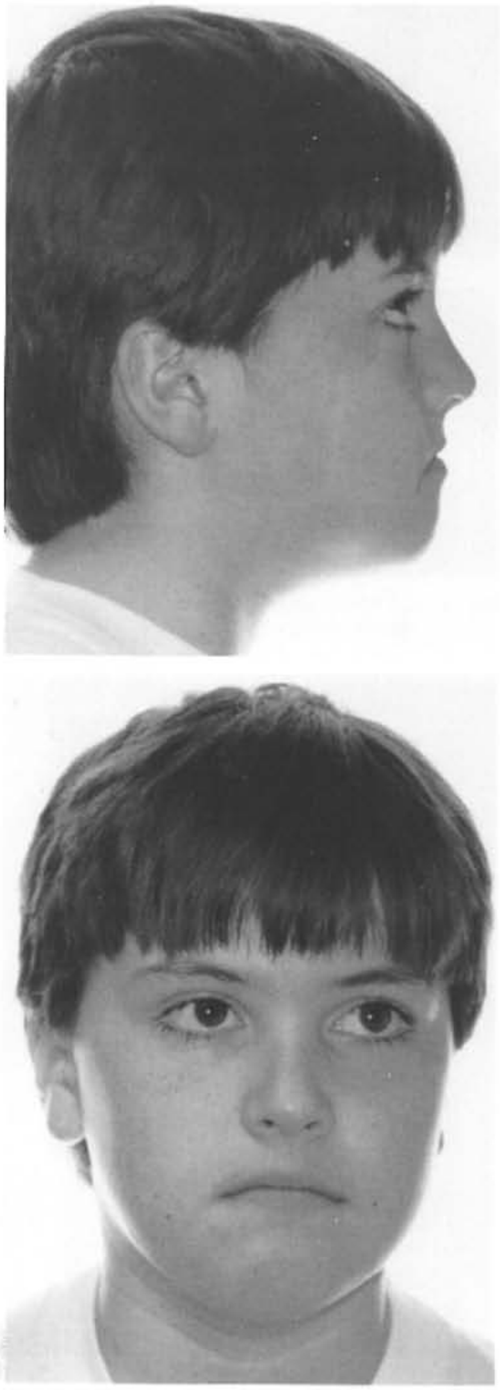


Fig. 31. T.J.B. Age 11 years. Beginning photographs.

Fig. 32. T.J.B. Age 11 years. Beginning intraoral photographs.

Fig. 33. T,J.B. Age 13 years. Finished intraoral photographs.

The Visual Treatment Objective to achieve lip balance and ideal functional occlusion required movement of the maxilla and/or maxillary teeth anteriorly 1mm. The mandibular alveolar bone and/or anterior teeth must be retracted 6mm. The net movement required of alveolar bone and/or teeth is 3.5mm. Extraction of maxillary second bicuspids and mandibular first bicuspids was indicated.

Fig. 34. T.J.B. Retention, age 13 years. Maxillary centrals and laterals bonded, transpalatal arch and buccal tubes for elastic wear if necessary. Mandibular cuspid to cuspid retainer with labial hooks for Class III wear if necessary.

Fig. 35. T.J.B. Age 14 years. I year post treatment extraoral photographs.

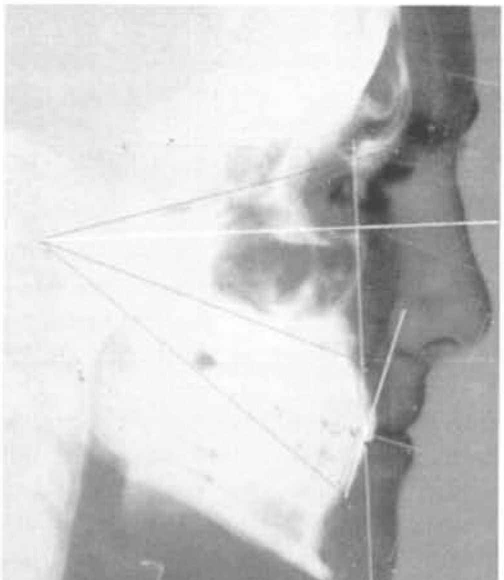


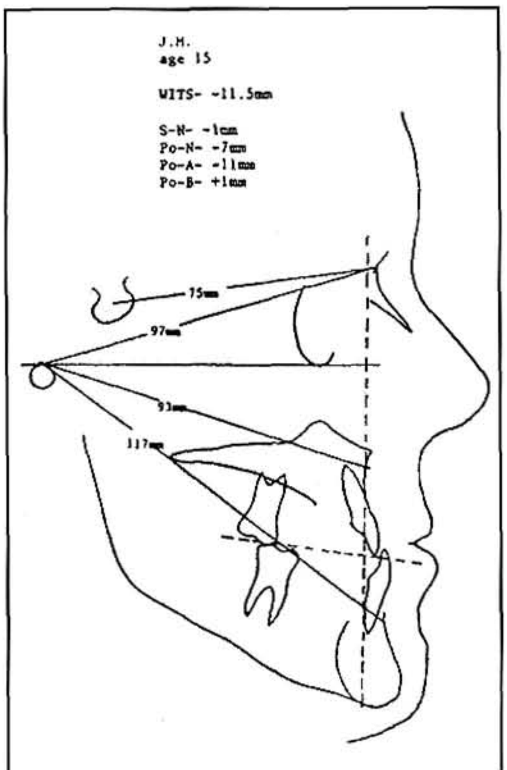
Fig. 36. Post finish cephalometric analysis of patient T.J.B.

Case study

J.M. Male, Age 15 years.

Clinical evaluation: Angle Class III, mandibular protrusion, maxillary cuspids were high and blocked labially, maxillary lateral incisors were excessively instanding, the anterior bite was open, all maxillary teeth were in lingual crossbite except cuspids and right first and second molars. This malocclusion has all characteristics outlined as occurring in Class III malocclusions with the EXCEPTION of an anterior deep bite.

APPLYING THE DUAL PLANE ANALYSIS TO A CLASS III MALOCCLUSION



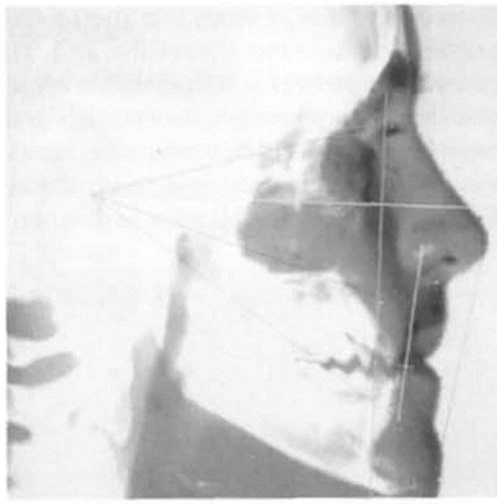


Fig. 37. Diagram of patient J.M. indicating the antero-posterior positioning of 'N'.'A' and 'B' relative to Porion and Sella. The vertical dash line is point 'A' perpendicular which indicates the antero-posterior position of Nasion and Pogonion in mm to the true horizontal plane of the face (FH).

Frankfort horizontal has been accepted as the true horizontal of the face. The Wits measured -11.5mm. Nasion appears in good position antero-posteriorly to both Porion and Sella. The distance of Porion to 'A' point is 11mm less than standard for a 15 year old male, indicating a recessive maxilla. Porion to 'B' point is 1mm longer than normal, which would indicate normal length to 'B' point. A perpendicular line through 'A' point defines the position of Nasion (+2.5mm) and Pogonion (+10mm) antero-posteriorly to the maxillary base, which depicts an excessive growth of the chin (button). The mandibular central incisors were 3mm anterior to the AP line and the maxillary incisors were 1mm lingual to the AP line. Mandibular teeth and/or alveolar bone must be retracted 4mm and the maxillary incisors and/or alveolar bone must be moved anteriorly 2mm to establish normal incisal guidance. One half of the total 6mm of tooth movement (3mm) is needed to compensate for J.M.'s apical base

discrepancy. It is obvious that the profile presents a recessive maxilla and an excessively protrusive chin point. The apical base discrepancy between the maxillary and mandibular alveolar bone is minimum (3mm). If any surgery were done to improve profile, it should only be a modification of the chin.

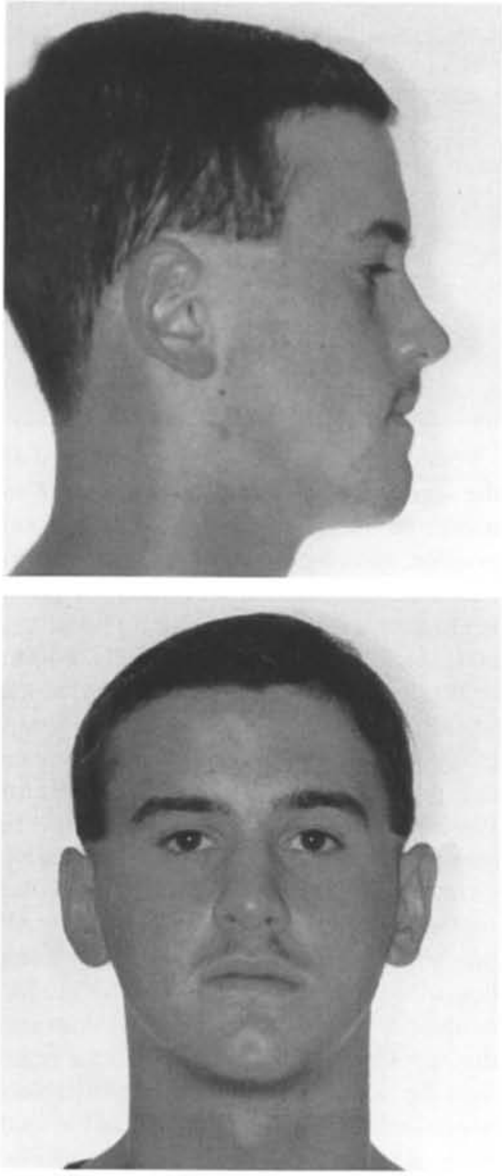


Fig. 38. J.M. Age 15 years. Beginning photographs.

Fig. 39. J.M. Age 15 years. Beginning intraoral photographs.

Fig. 40. J.M. Age 17 years. Finished maxillary arch, mandibular arch six months pre-finish.

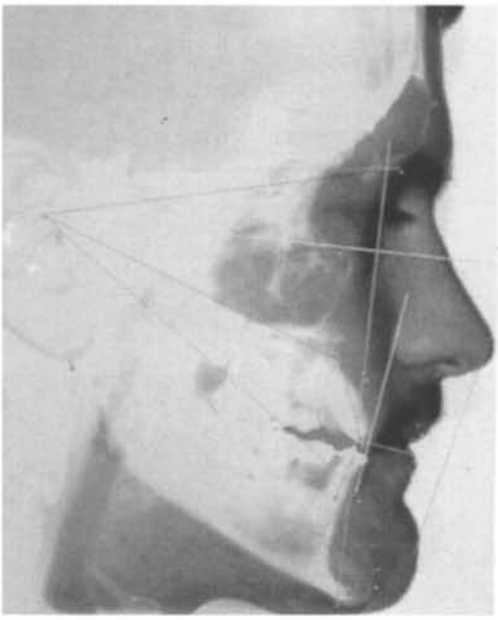


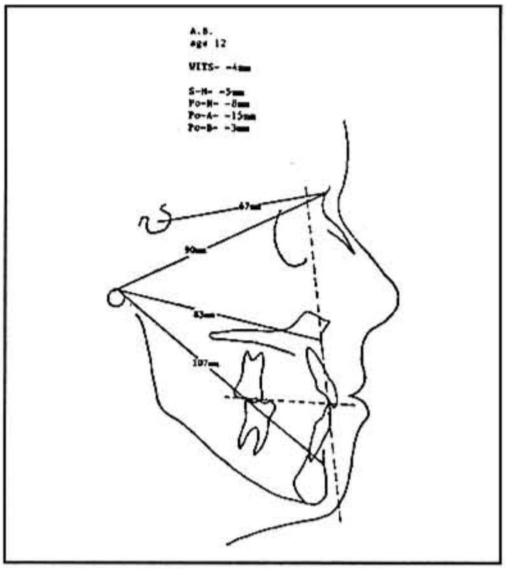
Fig. 41. J.M. Cephalometric analysis, six months pre-finish.

Case study:

A.B. Female, Age 13 years.

Clinical evaluation: Angle Class III, steep mandibular plane angle. extremely narrow maxillary arch with lateral incisors instanding. There was a submucousal cleft of the palate.

APPLYING THE DUAL PLANE ANALYSIS TO A CLASS III MALOCCLUSION



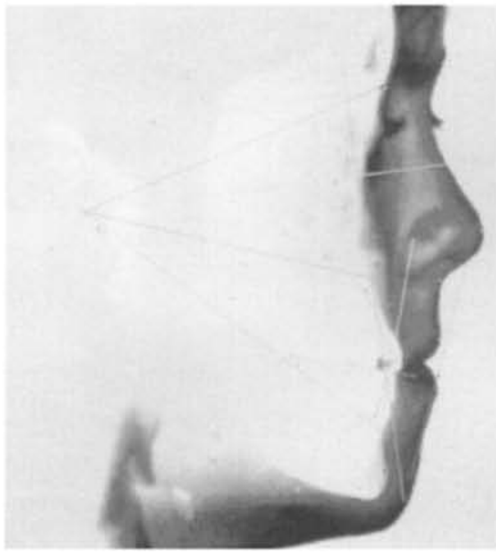


Fig. 42. Diagram of patient A.B. indicating the antero-posterior positioning of 'N'. 'A' and 'B' relative to Porion and Sella. The vertical dash line is point 'A' perpendicular which indicates the antero-posterior position of Nasion and Pogonion in mm to the true horizontal plane of the face (FH).

Frankfort horizontal has been accepted as the true horizontal of the face.[1] The Wits measured -4mm. The distance of Sella to Nasion is -5mm, Porion to Nasion is -8mm and Porion to 'A' point is -15mm. These measurements indicate a recessive midface for a female of this age. A perpendicular line through 'A' point defines the position of Nasion (+8mm) and Pogonion (-4mm) antero-posteriorly to the maxillary base. The mandible's length (-3mm Porion to 'B' point) indicates that the mandible was slightly short. The mandibular central incisors were on the AP line and the maxillary central incisors were 5mm anterior to the AP line. The maxillary incisors required retraction of 4mm.

Fig. 43. A.B - Age 13 years. Beginning photographs.

TREATMENT PLAN

Fig. 44. A.B - Age 13 years. Beginning intraoral photographs.

Expand maxillary arch 8mm in cuspid area and 13mm in first molar area. Expand mandibular arch 5mm in cuspid area and 3mm in molar area. Construct an ideal maxillary and mandibular arch form. Produce a parabolic maxillary anterior arch with incisor roots aligned in the channel of bone.

Fig. 45. A.B - Age 15 years. Finished photographs.

Fig.46. A.B - Age 15 years. Finished intraoral photographs.

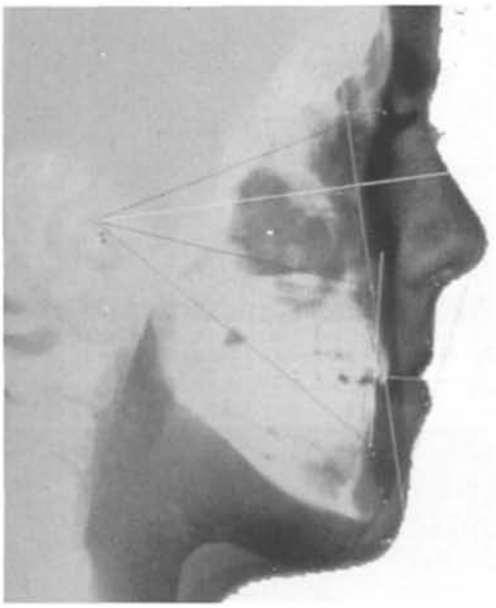


Fig. 47. A.B. Post finish cephalometric analysis of patient.

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19
Retention

John P Fricker

INTRODUCTION

Retention can be defined as "the holding of teeth in idealistic and functional positions"(Joondeph and Riedel 1985). It is generally accepted that teeth that have been moved orthodontically will drift back towards their original position if left unsupported. Thus in the majority of cases a phase of retention is indicated to minimise this tendency.

It is essential that retention be considered as part of the diagnosis and treatment plan as the requirement and duration of retention is dependent on what orthodontic/orthopaedic movements are carried out during treatment. Indeed there are some orthodontic movements that require no retention at all.

Retention is often associated with achievement of a stable orthodontic result. However, stability is a misnomer, as once the appliances are removed the teeth are exposed to a natural environment of muscular pressures, occlusal forces and the physiological changes coincident with normal growth and/or aging. Final positions of teeth are not static as the functional occlusion is dynamic and such positions will change in response to pressures on the periodontal ligament. Retention is thus aimed at maintaining newly established positions until the soft tissues have adapted and the periodontal tissues have reorganised. Such retention should continue until the major growth changes have ceased.

Reorganisation of the Periodontal Tissues

Widening of the periodontal ligament space and disruption of the collagen fibre bundles that support each tooth are normal responses to orthodontic treatment. These changes are necessary to allow orthodontic tooth movement to occur. Restoration of the normal periodontal architecture will not occur if a tooth is strongly splinted to its neighbours, therefore passive archwires cannot be considered the beginning of retention. Once the teeth can respond individually to the forces of mastication, reorganisation of the periodontal ligament (PDL) occurs over a 3 to 4 month period (Reitan 1969) and the slight mobility present at appliance removal disappears. Immediately after orthodontic appliances are removed, teeth will be unstable in the face of occlusal and soft tissue pressures, thus every patient should wear removable retainers for at least a few months before fitting a fixed retainer.

The gingival fibre networks are also disturbed by orthodontic tooth movement and must remodel to accommodate the new tooth positions. Both collagenous and elastic fibres occur in the gingiva, and the reorganisation of both occurs more slowly than that of the PDL itself (Reitan 1959). Within 4 to 6 months, the collagenous fibre networks within the gingiva have normally completed their reorganisation, but the elastic supracrestal fibres remodel extremely slowly and can still exert forces capable of displacing a tooth up to a year after removal of orthodontic appliances. In patients with severe rotations, sectioning the supracrestal fibres around severely malposed or rotated teeth, at or just before the time of appliance removal, is a recommended procedure to reduce relapse tendencies resulting from this fibre elasticity (Edwards 1970, Boese 1980).

SURGICAL RETENTION PROCEDURES

Fiberotomy

The supra-alveolar soft tissues contribute to the relapse of orthodontically treated teeth, specifically, rotated teeth. (Reitan 1958, 1959, 1967). This fibre alteration does not lessen after long periods of retention. The marginal gingiva is pulled along with the tooth as it is rotated, and the fibres remain attached, which results in the displacement of the gingiva in the direction of the tooth movement. The circumferential supracrestal fiberotomy consists of inserting a surgical blade into the gingival sulcus, severing the epithelial attachment surrounding the involved teeth, and transecting the transeptal fibres (Edwards 1970).

This procedure should not be done during active tooth movement but toward the end of the finishing phase of active treatment and not in patients with moderate-to-severe gingival inflammation. To avoid gingival recession, the incising should not be done on the midlabial or midlingual portion of any tooth with a narrow zone of attached gingiva or a thin plate of cortical bone. It should extend at least one tooth mesially and distally to the rotated tooth or teeth. During gingival healing, retainers should be in place. Both short-term and long-term studies have shown that circumferential supracrestal fiberotomy reduce the mean relapse by almost 30% and completely eliminated severe and additional relapses (Edwards, 1993).

A modified procedure has been developed (*Fig. 1 a & b*) where a full periosteal flap is raised both labially and palatally then sutured through the contacts. This provides more predictable severing of all supracrestal fibres around individual teeth and has been shown to provide a more stable result following orthodontic extrusion of teeth (Weekes & Wong 1995).

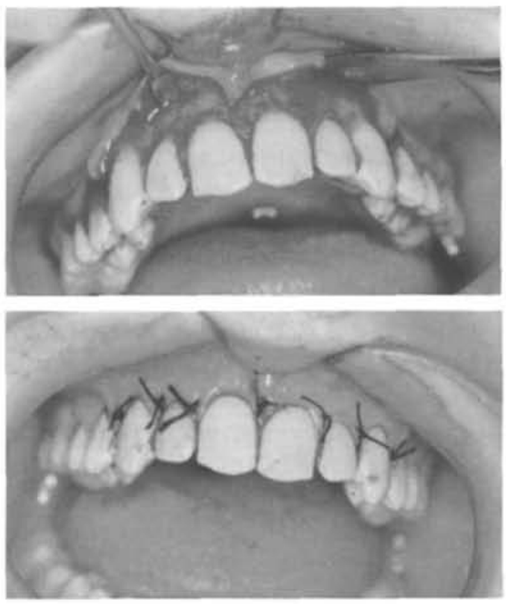


Fig. 1. A - Modified pericision showing a full periosteal flap raised from canine to canine. This is repeated on the palatal tissue.

B - Palatal and labial flaps are sutured into position.

As with all gingival surgery, good oral hygiene is essential for surgical healing. It is recommended that chlorhexadine mouthwashes be used daily from one week prior to surgery until one week post operative. Also antibiotic cover be prescribed for one week post-operatively.

Gingivoplasty

Surgical excision of excess gingival tissue that has not resorbed during treatment is recommended to lessen relapse in extraction sites. Gingival tissue accumulates between two orthodontically approximated teeth, and a vertical cleft in the buccal and lingual gingiva develops (Atherton 1970). Histologic studies of this gingival cleft or groove between two approximated teeth revealed an increase in the degree of keratinisation of the epithelium in the cleft. As a result of these histologic observations, Edwards (1970) recommends alleviating the relapse tendencies by a surgical gingivoplasty toward the end of active treatment. It should be used in conjunction with early and tight closure of the extraction site, proper root positioning, elimination of occlusal forces tending to separate teeth, and appreciation for any tooth size discrepancy in extraction areas.

Arch Expansion

Any malocclusion prior to orthodontic intervention is essentially stable. That is, the relationship of the maxillary dental arch to the mandibular arch whether in cross bite or positive overjet is representative of a balance within the surrounding muscles at the time. Angle (1907), proposed arch expansion and non-extraction treatment with a view to fitting all teeth in the dental arch as a routine course of treatment.

However, clinical research by Tweed (1944) and Begg (1954, 1961) indicated that pretreatment dimensions were inviolate and if it were not possible to align all teeth without increasing arch width or length then extraction of permanent teeth is justified. Correct diagnosis is critical and treatment of borderline space conditions without extraction must always take a calculated risk of relapse. Indefinite retention of arch expansion will expose the periodontal tissues to excessive stress. Discussion with the patient must include a realistic appreciation of relapse of a well aligned arch, particularly of lower incisors. Acceptance of some minor crowding of lower incisors is a valid option as opposed to over extraction while still achieving a functional and aesthetic result.

Arch length will decrease with time post treatment, regardless of the treatment modality (Shapiro 1974, Kinne 1975, Little *et al.*, 1988, 1990). The intermolar width also decreases post treatment (Shapiro 1974). An increase in the intercanine width during treatment will often be followed by post treatment decreases to less than the original intercanine dimension. The intercanine width typically decreases with time whether treated extraction or nonextraction or had no treatment (Strang 1949, Steadman 1961, Herberger 1981, Little *et al.*, 1988, 1990).

Growth Changes

The direction of facial and in particular mandibular growth will directly affect the final result of a treated malocclusion. Vertical growers are the most difficult to treat as the mechanics of orthodontic and orthopaedic treatments show more predictable results when treating horizontal discrepancies. When such growth continues into retention horizontal growth is seen as a more favourable growth vector than vertical growth. Class II problems with a skeletal component maybe either maxillary protrusion or mandibular retrognathia. A horizontal growth pattern will improve the

anterior posterior relationship and retention should be aimed at supporting the original diagnosis of the skeletal imbalance, ie, with maxillary protrusion retention is aimed at limiting forward growth of the maxilla and in mandibular retrognathia, holding the mandible forward. In either case, a locked in occlusion with canine function will help to maintain the occlusion. Removable appliances that allow 'settling' of the dentition into occlusal function are preferred to appliances that cover the occlusal surfaces.

Extra oral traction may also be indicated on night time basis to hold the maxillary arch and functional appliances to stabilise the forward posture of the mandible are indicated in cases of retrognathia until the end of growth and the occlusion well settled in.

Overbite

Excessive overbite often accompanies Class II malocclusion. Whether the overbite has been reduced during active treatment by incisor intrusion or molar elevation (or combination of both) such a correction requires support during the retention phase. The simple method is to build in an anterior bite platform into the removable appliance so that when worn, the mandibular incisors contact the acrylic with the posterior teeth in light occlusal contacts. This will allow remodelling and reorganisation of periodontal tissues in the posterior segments without intrusive forces of occlusion to increase the overbite.

Class II, Division II cases present with retroclined maxillary incisors, particularly the central incisors. Retention is dependent on the final torque of these teeth to an obtuse interincisal angle of between 125-135°. This will limit over eruption of maxillary incisors post treatment and relapse of the overbite. Once again, diagnosis of the original malocclusion is critical as to whether treatment requires the intrusion of maxillary incisors to correct the overbite.

Removable appliances with close contact over the palatal surfaces of maxillary incisors will limit the post treatment retroclination of these teeth and maintain the interincisal angle.

Class III Malocclusion

The mandible is normally the last of the facial bones to stop growing, and excessive growth in these later stages can produce a Class III relationship too severe for orthodontic correction. Class III diagnosis and treatment planning will determine the extent of and skeletal discrepancy from the cephalometric analysis. Clinical judgement will then decide on orthodontic camouflage to procline upper incisors and retrocline lower incisors to an acceptable functional occlusion or surgical osteotomy.

Diagnosis of a Class III pattern should include an assessment of the skeletal discrepancy and a forecast of continued mandibular growth, be it in a vertical or horizontal direction. Vertical discrepancies are often accompanied by an anterior open bite in conjunction with cross bite while horizontal growth discrepancies are manifested in anterior cross bites.

Non surgical treatment of open bites is essentially extrusion of incisors and intrusion of molars. Retention is aimed holding overcorrection to accommodate future growth and limiting active habits such as thumb sucking or tongue thrusting which will result in the opening of the bite. Open bites are difficult to control as vertical growth can often continue until late teens or early twenties.

Lower Incisor Crowding

Lower incisor crowding is also a manifestation of continued mandibular growth (Bjork 1963, Little *et al.*, 1981) as the mandibular incisors will migrate mesially with continued growth. When confined in a positive overbite and overjet the contacts may slip to produce a variable amount of crowding (Bishara *et al.*, 1973).

CLINICAL APPLICATIONS

Retention planning is divided into three categories, depending on the type of treatment instituted: (1) no retention; (2) limited retention, in terms of both time and appliance wearing; (3) permanent or semipermanent retention.

1. No retention required

a. Corrected crossbites in the mixed dentition

   i. Anterior: when adequate overbite has been established

   ii. Posterior: when axial inclinations of posterior teeth remain reasonable after corrective procedures have been completed (It may be suggested in regard to posterior cross bites that overcorrection is a desirable procedure.)

b. Following space regaining once the blocked out tooth has erupted into correct occlusion.

2. Limited Retention (Most typical orthodontic cases probably fall into this category. Many corrections require time to allow muscular adaptation and sometimes to maintain the correction until growth has been completed).

a. Class I nonextraction cases characterised by protrusion and spacing of maxillary incisors (These require retention until normal lip and tongue function has been achieved).

b. Class I or Class II extraction cases (These probably require that the teeth be held in contact, particularly in the maxillary arch, until lip and tongue function can achieve a satisfactory balance, as in the nonextraction group. It is especially true in extraction cases that the maxillary incisors can be retracted so far as to be restrained by lip pressure and to impinge on the space occupied by the tongue before treatment.

c. Corrected deep overbites (In either Class I or Class II malocclusions, these usually require retention in a vertical plane (Magill 1960, Schudy 1968, Simons & Joondeph 1973).

   i. Where anterior teeth have been intruded a bite plate on a maxillary retainer is desirable. To be effective in retaining overbite correction, the bite plate should be worn continuously for the first 4 to 6 months, including while the patient is eating. It is in deep overbite cases that overcorrection is usually desirable and equilibration and adjustment to functional occlusion are necessary.

3. Permanent or semipermanent retention

a. Cases in which expansion has been the choice of treatment, particularly in the mandibular arch. In many instances patients have aesthetically desirable dentofacial relationships, and extraction of permanent teeth would create aesthetically undesirable results. The orthodontist may be faced with a choice between stability and aesthetics, and it is often the patient's aesthetic requirements that win out. Occasionally, mild mandibular crowding can be relieved by interproximal stripping whereas other cases will require that the patient wear

a retainer indefinitely if normal contact is to be maintained).

b. Cases of considerable or generalised spacing (These may require permanent retention after space closure has been completed. It is sometimes possible and desirable to accumulate excess space in the posterior segments and to place bridges to fill the excess thus created).

c. Instances of severe rotation (particularly in adults) or severe labiolingual malposition.

d. Spacing between maxillary central incisors in otherwise normal occlusions.

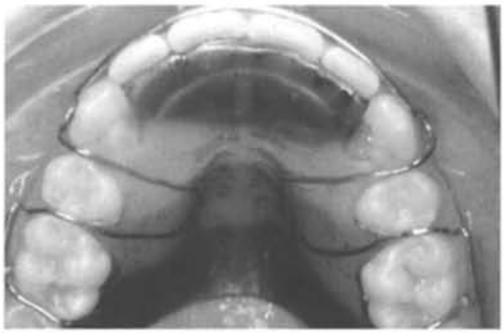
REMOVABLE APPLIANCES AS RETAINERS

Hawley Retainers

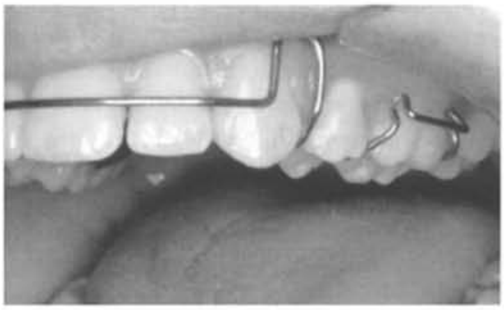
By far the most common removable retainer is the Hawley (1919) retainer, designed originally as an active removable appliance. It incorporates clasps on molar teeth and a characteristic outer bow with adjustment loops, spanning from canine to canine (*Fig. 2A & B*).

In some situations, in order to maximise the retention of a lower appliance it is best to use cribs which gain their retention from the lingual undercuts of the lower molars (Bell 1983, Sandler & Reed 1988).

There are several variations on the upper Hawley appliance. One variation utilises a reverse 'U' loop labial bow because this provides better control of the position of the canines. Another variation has the labial bow soldered to the cribs. This variant is particularly suitable in patients whose first premolars have been extracted. The labial bow on the standard Hawley retainer extends across the extraction space and tends to wedge it open, but this tendency can be prevented by using a labial bow soldered to the cribs.



A



B

Fig. 2. A & B - Hawley retainer with labial arch from canine to canine (0.8mm wire) Adams cribs on molars (0.7mm wire).

Bite planes may also be incorporated in to the Hawley appliance as a control for overbite. Maintaining an overbite in this way is not enough to ensure stability later; unless other dental or functional relationships are also changed, overbite will inevitably increase following removal of such an appliance.

The most useful application of the bite plane is following deep overbite correction which is accomplished initially with some degree of elevation of the buccal teeth (bite opening). A mandible thus opened will tend to gradually return to its original posture, once again 'closing the bite', so incisor overbite must be controlled during this stage if overbite relapse is to be avoided.

Applications

The Hawley appliance is used primarily to maintain individual tooth alignment or to make small changes in that alignment. It can be used alone or as a supplement to the rubber positioner or other appliances. An upper Hawley retainer may also be used in combination with different lower appliances such as the cemented lingual wire.

Care must be taken not to inhibit desirable tooth adjustments with this appliance. Changes in arch width in particular will be restricted by the buccal margins of the upper acrylic, so occlusal relations with the lower teeth should be carefully watched during this period and the appliance relieved as required.

The clasp locations for a Hawley retainer must be selected carefully, since clasp wires crossing the occlusal table can disrupt rather than retain the tooth relationships established during treatment. Circumferential clasps on the terminal molar or lingual extension clasps may be preferred over the more effective Adams clasp if the occlusion is tight.

Acrylic can be flowed over the labial arch to provide additional support, particularly where incisors were severely rotated pre-treatment (see spring aligner).

Adjustment of Hawley Retainers

Retention of Hawley retainers is via Adams cribs (Adams 1984) engaged into the embrasure at the gingival margin. Wire diameter of cribs should be 0.7 mm. The labial arch is fitted snugly across the middle of the incisors and ends at the U loop around the canines. The diameter of the labial arch is 0.8 mm. Adams cribs are adjusted by bending the arrow heads into the embrasure (*Fig. 3*) and the labial arch adjusted by lightly constricting the U loops at the canines.

Fig. 3. Adjustment of Adams Cribs. The arrow head is bent in towards the gingiva.

Barrer Retainer (Spring Aligner)

A second major type of removable orthodontic retainer is the wraparound or clip-on retainer, which consists of a plastic bar (usually wire-reinforced) along the labial and lingual surfaces of the teeth (Barrer 1975) (*Fig. 4A, B & C*). A full-arch wraparound retainer firmly holds each tooth in position. This is not necessarily an advantage, since one object of a retainer should be to allow each tooth to move individually, stimulating reorganisation of the PDL. In addition, a wraparound retainer, though quite aesthetic, is often less comfortable than a Hawley retainer and may not be effective in maintaining overbite correction.

A variant of the wraparound retainer, the canine-to-canine clip-on retainer, is widely used in the lower anterior region. This appliance has the great advantage that it can be used to realign irregular incisors, if mild crowding has developed after treatment but it is well tolerated as a retainer alone. It is quite feasible to use a wraparound anterior section to replace the wire bow of a lower Hawley retainer, if some control of posterior teeth is desired.

Spring aligners are retained via U loops both labial and lingual to the canines or premolars. Extension of the premolars is preferred as it provides greater stability of the anterior segment and the interproximal contours distal to the premolar provide a better retention contour than the distal of the canines.

Adjustment is by constricting the U loops with pliers or squeezing the loops bucco-lingually with light finger pressure.

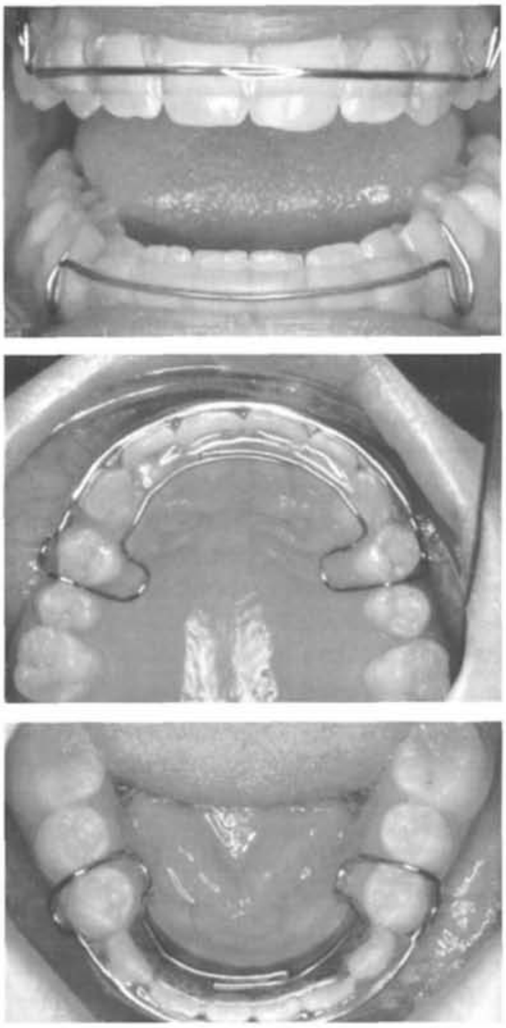


Fig. 4. A, B & C - Barrer type spring aligners. Extention with U loops to the premolars provide greater control over the anterior segment.

Realignment of Irregular Incisors: Spring Retainers

Recrowding of lower incisors is the major indication for an active retainer to correct incisor position. If late crowding has developed, it often is necessary to reduce the interproximal width of lower incisors before realigning them, so that the crowns do not tip labially into an obviously unstable position. The cause of the problem in these cases usually is late mandibular growth, which has uprighted the incisors, and they must be realigned in their more upright position. Not only does stripping of contact reduce the mesiodistal width of the incisors, decreasing the amount of space required for their alignment, it also flattens the contact areas, increasing the inherent stability of the arch in this region. As with any procedure involving the modification of teeth, however, stripping must be done cautiously and judiciously. It is not indicated as a routine procedure (Gilmore and Little 1984).

Interproximal enamel can be removed with either abrasive strips of thin discs in a handpiece. Obviously, enamel reduction should not be overdone, but if necessary, the width of each lower incisor can be reduced up to 0.5 mm on each side without going through the interproximal enamel. If an additional 2 mm of space can be gained, reducing each incisor 0.25 mm per side, it is usually possible to realign typically crowded incisors.

A spring aligner can be used to realign crowded incisors. The steps in making such an active retainer are: (1) reduce the interproximal width of the incisors and apply topical fluoride to the newly exposed enamel surfaces; (2) prepare a laboratory model, on which the teeth can be reset into alignment; and (3) fabricate a premolar to premolars. appliance.

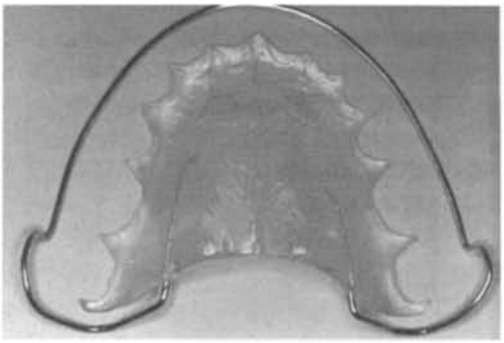
Any active removable appliance can be used as an active retainer to recover the position of teeth that have relapsed after orthodontic treatment. Only minor relapse should be observed after correctly planned comprehensive treatment, which means that the inherent limitations of removable appliances should not be exceeded by the demands on them in active retention. If there is more than a modest degree of relapse, placing a fixed appliance for comprehensive retreatment must be considered.

Begg Retainer

An alternative to the Hawley retainer is the wraparound or 'Begg' retainer (Begg 1963) (*Fig. 5*). This retainer has no cribs - thus minimising the amount of wire crossing between contact points and maximising the potential for the occlusion to 'settle' during the retention period. The disadvantage of this design is that a long length of wire is incorporated into the labial bow, which can be easy to distort and difficult to adjust. However, this can be overcome by using wire of 0.9 mm or 1.00 mm diameter.

An advantage of this design over the Hawley retainer is that its wire does not keep crowns of upper premolars and canines apart. Another advantage is that its wire can be used to tip the crowns of canines, premolars and molars slightly lingually whenever this tipping is required.

When first premolars have been extracted, one function of a retainer is to keep the extraction space closed, which the standard design of the Hawley retainer cannot do. The standard Hawley labial bow extends across the first premolar extraction space, tending to wedge it open.



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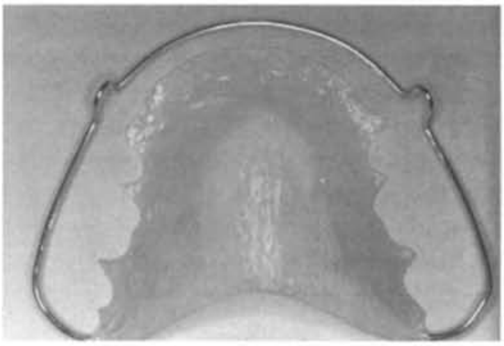


B

Fig. 5. A - Begg retainer. Archwire extends distal to the last molar and enter the acrylic palatally.

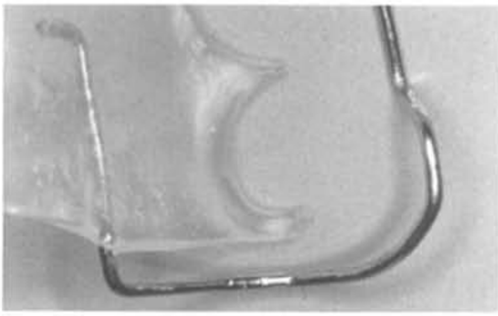
B - Begg retainer. Archwire extends distal and the last molar and enters the acrylic from the buccal. U loops at the canines allow for adjustment.

Adjustment of Begg retainers

Retention of the Begg retainers is by means of the engagement of the arch wire around the last molar. When first fabricated the wire should sit passively, but snugly across the middle of the incisors and carry through to the molars.

U loops may be added distal to the canines to allow adjustment as per a Hawley or alternatively adjustment is constricting the labial arch with light finger pressure (*Fig. 6 A, B & C*) towards the posterior border of the appliance.

A



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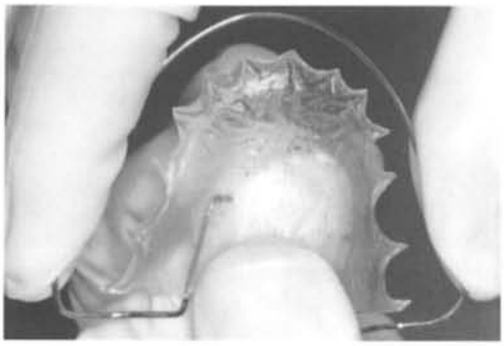


C

Fig. 6. A - U loops are adjusted by lightly squeezing the loop closed.

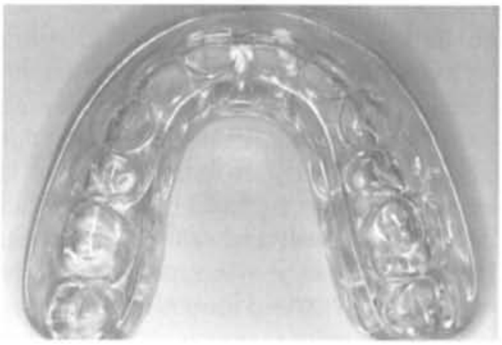
B - Distal wire wraps around the last molar and extends into the palatal acrylic.

C - Palatal archwire are adjusted with finger pressure. Hold the palatal acrylic and while supporting the archwire at the molar bends along the plane of the wire towards the distal.

Positioners

The tooth positioner was developed by Dr Kesling (1945) as a one piece resilient appliance made from rubber. It is made to cover the clinical crowns of the teeth fitting the free way space and extending over the attached gingiva (*Fig. 7A & B*).

The positioner is constructed over a predetermined set up where teeth can be sectioned from plaster casts and waxed into ideal occlusion. The positioner is then formed from elastic (mouthguard) material over the casts, holding the arches slightly apart. Such a positioner can control space closure and stabilise overbite correction.



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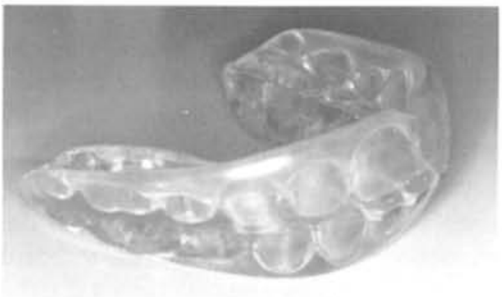


B

Fig. 7. A & B - Preformed tooth positions (T-P prefinishers).

The patient is instructed to exercise into the positioner in 10 to 20 second bursts for up to four hours per day and to sleep with it in. This will stimulate the periodontal tissues and encourage remodelling and reorganisation of tissues following fixed appliance therapy. The appliance should be worn for at least four weeks with active chewing into it and then night wear before either going to removable acrylic retainers or continuing 12 months of sleep wearing only.

Preformed 'Prefinishers' are available as off the shelf positioners in a range of sizes according to arch perimeter length and various extraction and non extraction finishes.

Fixed Retention

Fixed retention should not be placed immediately after fixed appliances are removed as at least a week is required with the teeth under physiological tension to allow the PDL to reorganise (Reitan 1959)

Fixed retainers are useful whenever prolonged retention is advisable, for example:

- where teeth have been derotated
- where spaces have been closed
- where periodontal support is reduced
- where the overbite remains reduced at the end of treatment and the upper incisors remain at risk of relapsing into a reversed overjet.

Fixed Retainers in Adolescence

Another reason for choosing a fixed retainer is to ensure that the alignment of the lower labial segment remains stable throughout late adolescence. This is a time when dentoalveolar adaptation occurs as a response to the late stages of facial growth. The dentoalveolar adaptation which occurs usually maintains existing occlusal relationships despite further growth. During late adolescence, the maxilla is relatively stable but the mandible may continue to grow downwards and anteriorly. Since the lower dentition is usually confined within the upper dentition, further mandibular growth results in the lower dentition taking up a smaller arch length and the upper dentition 'yielding' and taking up a greater arch length, or a combination of both (Bishara *et al.*, 1973). Without a retainer, dentoalveolar adaptation for continued forward growth of the mandible maybe manifested by retroclination of the lower incisors maintaining a positive overjet at the expense of slipped contact points. The incisors then occupy a smaller arc of a circle, producing a variable degree of crowding.

Bonded Fixed Retention

In the last 10 years, reports on bonded fixed retainers have employed multistrand wire and two different types of bonded fixed retainer with multistrand wire have evolved: the canine-to-canine bonded fixed retainer; and the flexible wire bonded fixed retainer. In the former a relatively rigid large diameter multistrand wire, usually 0.032 inch, is bonded to the canines only. In the latter type a smaller diameter multistrand wire, usually 0.0175 inch or 0.0215 inch, is bonded to each tooth in the labial segment. In this situation advantage is taken of the flexibility of this wire in addition to the surface roughness of the wire.

As an alternative to multistrand wire, the use of resin fibreglass strips has been developed (Diamond 1990, Orchin 1990). The fibreglass strips are soaked in composite and bonded to acid-etch enamel. Although this technique has the advantage of reducing the bulk of the retainer, it has the disadvantage of creating a rigid splint, which limits physiologic tooth movement and contributes to a higher failure rate.

Indications for bonded retainers

The indications differ between the canine-to-canine bonded retainer and the flexible wire bonded retainer.

Lee (1981) considered the following to be indications for placement of a bonded canine-to-canine retainer:

1. Severe pretreatment lower incisor crowding or rotation;
2. Planned alteration in the lower intercanine width;
3. After advancement of the lower incisors during active treatment;
4. After nonextraction treatment in mildly crowded cases;
5. After correction of deep overbite.

The flexible wire retainer appears to have different indications for clinical use.

Zachrisson (1983) listed the following:

1. Closed median dastemas;
2. Spaced anterior teeth
3. Adult cases with potential postorthodontic tooth migration;
4. Accidental loss of maxillary incisors, requiring closure, and retention of large anterior spaces;
5. Spacing reopening, after mandibular incisor extractions;
6. Severely rotated maxillary incisors;
7. Palatally impacted canines.

The main indications for the canine-to-canine retainer are related to alteration of the anteroposterior or lateral position of the lower labial segment during treatment. The flexible wire retainer is indicated in those situations where individual tooth movements are prone to relapse. Interestingly the latter concur with Reitan's (1969) histologic findings on situations where the periodontal ligament fibres are taut and directionally deviated after treatment.

Techniques for construction of bonded retainers

Authors have suggested many variations in the design of bonded fixed retainers. These include different wire types with differing diameters, different composites, (Rubenstein 1976, Carter 1978, Lubit 1979, Lee 1981, Zachrisson 1977, Eade 1980) the use of mesh pads (Chan & Andreasen 1975, Klassman & Zucker 1976, Greenfield & Nathanson 1980), extracoronal ligation with composite(Ciancio & Nisengard 1975), the use of mesh alone with composite (Gazit & Liberman 1976) and the use of resin fiberglass strips (Diamond 1990, Orchin 1990).

Construction of a bonded fixed retainer might appear to be simple, but if good long-term success is to be ensured, meticulous attention to detail is required (Zachrisson 1983). Direct and indirect techniques have been described.

The direct technique requires a length of wire to be prefabricated to accurately fit a recent cast. Loops are not required at the ends of the wire (Zachrisson 1983). The adaptation of the wire is checked clinically to ensure it locates passively against all tooth surfaces to be retained. Inadvertent activation of the multistrand wire is a major concern and is to be avoided. The teeth are subsequently pumiced and acid etched for direct bonding of orthodontic attachment. The wire is then accurately located on the teeth. At this point authors differ in their approach, and many methods for locating the wire have been described. These include the use of dental floss (Zachrisson 1983, Orsborn 1983, Paulson 1992), orthodontic elastics (Carter 1978, Meyers & Vogel 1982, Read 1984) wire ligatures, wires tack welded to the retainer wire (Zachrisson 1977, Adenwalla & Attarzadeh 1986), localizing devices (Lubit 1979, Eade 1980, Hobson & Eastaugh 1993). Some authors recommend that a small amount of composite is used to tack the retainer in place at each end before adding

the bulk of material (Artun & Zachrisson 1982, Zachrisson 1983, Dahl & Zachrisson 1991). The composite can be shaped with an instrument dipped in unfilled resin or alcohol to produce the desired contour.

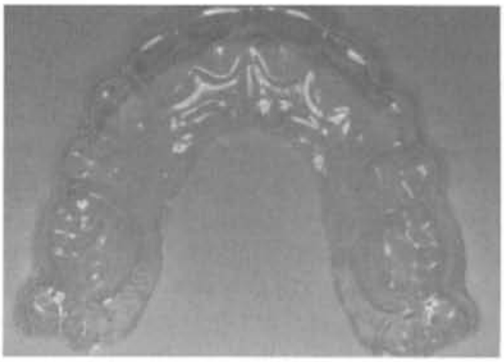
The use of an indirect technique has been described to simplify the clinical procedure (Ferguson 1987, Bantleon & Droschi 1988). The wire is prepared on the model, and inlay wax placed in the sites for the composite. A silicone impression material is placed over this and allowed to set. The wax is removed with boiling water. The teeth are prepared in the usual way, and the composite is placed in the voids left by the wax. The impression complete with the retainer wire and composite is then placed over the teeth and held firmly in position until the composite has set.

This indirect technique can be modified by placing composite directly on the model in place of the wax, allowing the composite to set, then covering this with a vacuum-formed plastic sheet for subsequent location of the unfilled resin bonding agent that is then used to bond the retainer to the enamel (Corti 1991).

Clear Overlay Retainers

Vacuum formed acrylic retainers provide a full cover over the palatal occlusal and lingual surfaces (*Fig. 8A, B & C*). These provide excellent retention of final tooth position but do not allow settling of teeth into occlusion as per a Hawley or Begg appliance (Sauget *et al.*, 1997) Physiological stimulation of the periodontal tissues once fixed appliances have been removed, is limited, restricting the remodelling and reorganisation of these tissues.

While providing an aesthetic appliance which is particularly attractive for adults, the acrylic material does not allow for any adjustment of fit. Because of the brittle nature of the material, they are prone to facture over the occlusal surfaces and require frequent replacement.



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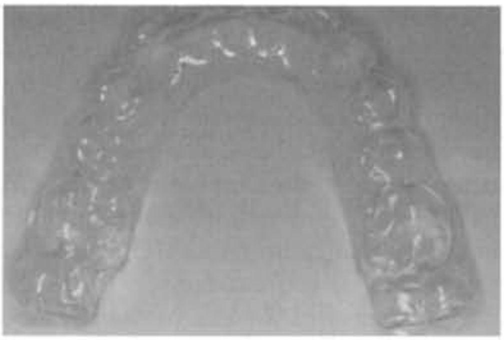

B

C

Fig. 8. A, B & C - Vacuum formed "suck down" retainers made from clear acrylic covering occlusal surfaces of all teeth.

DURATION OF RETENTION

As may be noted from the literature, various authors suggest a range of retention times from no retention (Englert 1960) to permanent retention (Little *et al.*, 1981). It is recommended that removable retainers be

full time for six months and removed for meals, cleaning and when playing contact sports or swimming. It is advisable that the appliances be checked within the first month of issue to monitor correct wearing and comfort, then checked each three months. It is during the first month that relapse tendency is the greatest and over the first six months that a support system is critical to facilitate remodelling and reorganisation of the periodontal tissues. Stimulus from mastication is essential during this period.

Removable retainers should then be worn each night (or during sleep hours) for a further six months and checked at three monthly intervals. Generally retainers should be worn part time, until all major growth is complete and a decision has been made as to whether third molars can erupt into occlusion or require removal. Beyond this time, it is by mutual consent between practitioner and patient to discontinue retention and leave the occlusion open to the natural environment of the mouth and to physiological changes due to maturation and aging.

Rigid fixed retainers should not be fitted immediately after removal of fixed appliances. Instead, removable appliances or semi-fixed appliances placed for at least 3 months to permit reorganisation and remodelling of periodontal tissues. If arch expansion and/or the patient demand fixed retention, then rigid fixed retainers can be fitted after this period.

The final decision to remove fixed retention must include counselling of the patient as to the prospect of further tooth movements. As stated previously, teeth will move and contacts will slip throughout life, especially where orthodontic treatment has included expansion of intercanine widths.

Conclusion

Retention is the most difficult stage of orthodontic treatment and must be planned for as part of the overall diagnosis and treatment plan (Huggins 1994). True stability where tooth positions are fixed for life is a physiological impossibility. One can only strive to produce an occlusion which is functionally stable within the oral environment. Keys to such stability are to:

- maintain the original dimension in intercanine width
- eliminate causes:
  - digit sucking
  - lip biting
  - tongue thrusting
- overcorrect
- achieve good interdigitation of cusps
- allow adequate time in retention for reorganisation of alviolar bone and periodontal tissues.
- precise root positioning

All orthodontic treatment produces a modelling and remodelling phenomena in the PDL. Following the completion of active treatment when orthodontic pressures are removed, teeth need to be exposed to physiological pressures of the oral environment to continue remodelling of PDL and bone. Therefore fixed retention where individual teeth are rigidly splinted, should not be fitted immediately after removal of fixed appliances. Instead removable retainers should be issued which are removed during eating and cleaning. The forces of mastication are then directed to the teeth and supporting tissues. If fixed retention is indicated, this should only be fitted after three months of removable appliance retention. Supercrestal fiberotomies will assist in reducing the chances of severely malposed or rotated teeth.

The natural physiology of aging is for a decrease in arch length. Trying to maintain such an arch length may create further problems. Perhaps one should recommend an orthodontic face lift every 10 years as part of the original treatment plan as expectations of lifelong stabilty are unrealitistic.

Few can have a perfect occlusion, but most can have a better occlusion. Tooth movement over time is a true fact of life, stability of tooth position is only post mortem.

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20 Materials in Orthodontics

John P Fricker

INTRODUCTION

Over the last 25 years there have been significant advances in dental materials. The application of new technologies to orthodontics has seen the development of a whole new range of wires based on titanium which has significantly improved the mechanics of orthodontic treatment.

The quest for an aesthetic appliance has encouraged the development of "clear brackets" based on ceramics. The rush to market these brought unique problems for the practitioner and manufacturers have responded with improved designs with greater safety margins built into them. The physical properties of ceramics demand alternative treatment mechanics in bonding and debonding as well as strategies to compensate for additional friction within the material.

Adhesive dentistry is the fundamental component of fixed appliance therapy. The acid etch technique has simplified fixed appliances as composite resins have been modified to provide reliable bonding. More recently, the development of glass-ionomer cements has revolutionised the bonding of brackets without acid etching as well as providing increased protection against decalcification.

Allergies to dental materials is becoming more prevalent in orthodontic practice. In particular, nickel and latex sensitivities should be part of the medical history taking.

WIRES

The mechanical properties of an archwire are an important consideration in the construction of both fixed and removable orthodontic appliances. There are five general wire alloys in significant current use: stainless steel, cobalt-chromium-nickel, titanium molybdenum (ß titanium), nickel titanium and recently aluminium titanium (α titanium) has been introduced.

In general, one should consider the following aspects in the selection of wires: force delivery characteristics, elastic working range, ease of manipulation by permanent deformation to desired shapes, capability of joining individual segments to fabricate more complex appliances, corrosion resistance/ biocompatibility in the oral environment and cost. An essential requirement of any wire is that it is biocompatible and this includes sensitivity and tolerance of the oral tissues to elements within the wire. Sensitivity and allergies to metals will be discussed later in this chapter.

TABLE 1

Basic Property plot	Location on bending	Equivalent terms
Rate of force delivery (stiffness)	Slope of elastic loading curve or unloading curve	$\frac{\text{modulus of elasticity x moment of inertia}}{\text{segment length}}$
Yield Strength (Stress)	Maximum bending movement or force before permanent deformation begins (vertical axis of graph)	Elastic Limit
Working range	Maximum value of purely elastic deformation (horizontal axis)	-
Modulus of resilience (resilience)	Area under elastic loading curve or unloading curve	$\frac{\text{Yield Strength}^2}{\text{2 x modulus of elasticity}}$
Springback	Elastic strain recovered on unloading after permanent deformation	$\frac{\text{Yield Strength}}{\text{modulus of elasticity}}$

The following characteristics of orthodontic wires are those with particular clinical significance (Wilcock 1989, Kapila and Sachdeva, 1989).

Environmental stability, refers to corrosion resistance and maintenance of desirable properties of the wire for extended periods after the date of manufacture. Hydrogen makes titanium alloys more brittle and unable to undergo plastic deformation without fracture. Hydrogen solubility in α titanium alloys is considerable (>9000ppm). Hydrogen solubility in ß Titanium alloys is much less (20-30ppm).

Stiffness is the load deflection rate and is proportional to the modulus of elasticity of the metal. It is a measure of the force required to deform a wire a set distance without plastic (permanent) deformation and is proportional to the 4th power of the diameter. (Table 1)

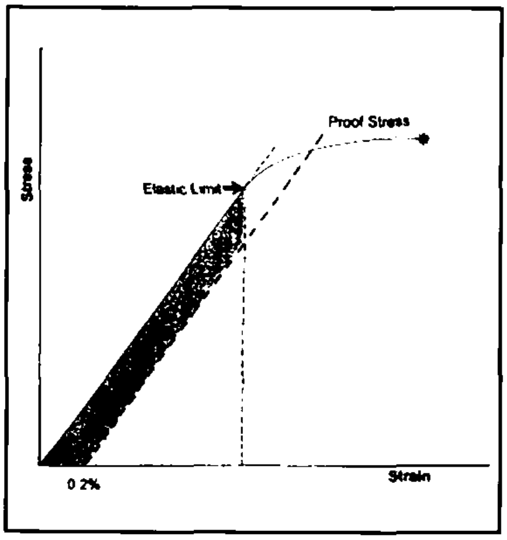


Fig. 1. The stress-strain diagram, showing the amount of deformation (strain) produced at each level of force (stress). The arrow indicates the elastic limit, beyond which the material will be subjected to a permanent set. The star is the point at which the test piece breaks. The shaded area under the graph is a measure of resilience.

Wire stiffness or elastic force delivery is dependent on two fundamental factors: (1) the composition and structure of the wire alloy, reflecting both the basic metallurgy and the wire manufacturing sequence, and (2) the wire segment geometry, i.e., the cross-section shape and size and the segment length.

Springback also described as:

- maximum flexibility
- maximum elastic deflection
- range of activation
- range of deflection
- working range

It is a measure of how far a wire can be defected without causing plastic (permanent) deformation and is the ratio of yield strength to the modulus of elasticity. Higher springback values provide the ability to apply large activation with a resultant increase in working time of the appliance, i.e. more time between appointments. (Table 1)

Formability is the ability to bend a wire into desired configurations such as loops, without fracturing and is related to the ductility of the wire. Formability is related to the percentage elongation a wire can undergo before fracture. This is shown on the stress strain graph by the length of the curve beyond the yield point up to fracture. Generally wires with high yield stress have low formability. Formability is desired property outside the mouth but not for appliance activation.

Friction is when two surfaces are pressed together with a perpendicular or normal force, another force acting parallel with these surfaces is required to cause one of these to move with respect to the other. This is due to the phenomenon of friction. Frictional force is the force required to move a body against the resistance due to friction. A numerical figure that is fairly characteristic of the two surfaces being placed together is the coefficient of friction.

Friction interests the orthodontist because it is present in the brackets and tubes through which wires must slide. The greater the pressure component against the inside of the bracket or tube, the greater will be the force required to make the wire slide. It is this characteristic of a frictional force that must be remembered when one is preparing arch wires which must slide or which will have attachments that slide upon them.(Jarabak & Fizzell 1963)

Two factors determine friction:

1. frictional coefficient of the surfaces in contact
2. total force between the surfaces

The area of contact is ***not*** a factor as increasing this area reduces the force per unit area in an equal and opposite measure. The important variable is the force generated between the wire and the slot, particularly as the tooth is uprighted or retracted (Fig. 2).

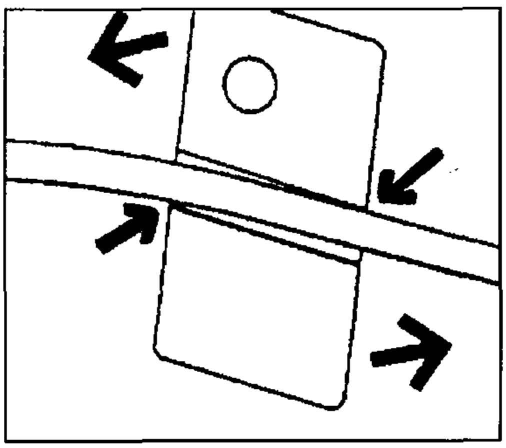


Fig. 2. Friction increases between the wire and the slot at the mesial and distal margins as a tooth is uprighted or retracted.

Strength is the total load carrying capacity of a wire when loaded as a beam. This depends on the working range (spring back) and the stiffness of the wire. Strength is proportional to the 3rd power of the diameter of the wire. (Table 1)

Resilience represents the work available to move a tooth. It is the amount of energy required to deform a wire elastically, i.e. without permanent (plastic) deformation. The slope of the line in the stress strain curve gives a measure of the modulus of elasticity (Fig. 1). The stiffer the wire, the less it can be deflected and thus the less energy can be stored. Where high resilience is required, a wire with a high yield stresses or low modulus of elasticity (or combination) is selected. The degree of resilience is represented by the area under the straight line portion of the stress strain curve. (Fig. 1).

Capability of welding or soldering or joinability. Welding is a metallurgical bond by localised melting without the use of a second alloy. Soldering uses a metal with a lower melting point to form a metallurgical bond.

Classification of orthodontic wires is based on tensile strength. With tensile testing, the entire length of the wire is subjected to the same strain or elongation to reach the elastic limit and is represented by the stress strain graph. (Twelftree, 1977) (Fig. 1). Tensile strength is not a significant factor in orthodontics as wires are not loaded in tension.

In practice the useful range of activation of a wire is limited by the point at which a wire ceases to behave in an elastic manner and starts to show permanent deformation. This point is the yield stress of a wire or the elastic limit. A line parallel to the elastic loading line and displaced by a distance equal to 0.2% strain will intersect the stress strain curve at a point known as the "Proof Stress" (Fig. 1).

Yield stress and proof stress values are more appropriate indicators for orthodontic wires than tensile strengths. Proof stress is the more reliable measure of the two.

Beam testing: In bending, the outer layers of the wire are strained, i.e. either stretched or compressed, while the inner layers towards the centre of the wire have less strain. The outer layers will reach the elastic limit and permanently deform while the inner layers will still behave elastically. The straight line of the stress bending curve will end when the outer layers deform.

The stress bending curve represents the actual response of a wire under clinical loading. Beam testing will provide measures of stiffness, resiliency and flexibility which reflect more closely those properties of wires which are applicable to the clinical situation.

Stainless Steel

Stainless steel wires are currently the most commonly used wires in clinical orthodontics because of their outstanding combination of mechanical properties, bioinertness and corrosion resistance in the oral environment and low cost. The wires are generally American Iron and Steel Institute (AISI) types 302 and 304 austenitic stainless steels, with similar nominal compositions. Type 302 is composed of 17% to 19% chromium, 8% to 10% nickel, and 0.15% maximum carbon. Type 304 contains 18% to 20% chromium, 8%-12% nickel, and 0.08% maximum carbon. The balance of the alloy compositions (Table 2) is essentially iron (approximately 70%). These are the "18-8" stainless steels, so designated because of the percentages of chromium and nickel in the alloys.

Austenitic stainless steel wires were introduced in the 1930's and replaced the use of gold archwires in orthodontics. Further research by Begg and Wilcock saw the development of high tensile resilient stainless

TABLE 2

Wire Alloy	Weight percentages of elements
Austenitic stainless steel	17%-20% Cr, 8%-12% Ni, 0.15% C maximum, balance principally Fe (approx. 70%)
Cobalt-chromium-nickel (Elgiloy)	40% Co, 20% Cr, 15% Ni, 15.8% Fe, 7% Mo, 2% Mn, 0.15% C, 0.04% Be
Alpha titanium	90% Ti, 6% Al, 4% V
Nickel-titanium (Nitinol)	52% Ni, 45% Ti, 3% Co
Beta titanium (TMA)	79% Ti, 11% Mo, 6% Zr, 4% Sn

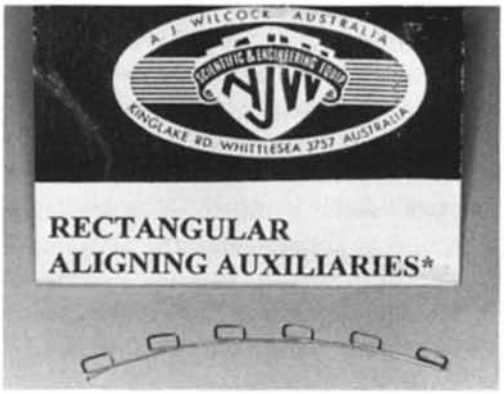


Fig. 3. 0.010" resilient stainless steel aligning auxiliaries

steel wires in the 1950s (Wilcock, 1989). Other alloys with desirable properties for orthodontics are cobalt chromium, nickel titanium, aluminium titanium (a titanium) and titanium molybdenum (ß titanium).

High tensile stainless steel spring wire can be formed with loops with care. However the advantage of high resilience is opposed by a disadvantage of brittleness which increases as the grade of wire increases. Wilcock Australian wire is one of the best stainless steel wires available for orthodontics. Its high resilience makes it ideal for levelling the curve of Spee and overbite reduction and this wire does not distort easily in the mouth. These wires are available in diameters from 0.009 to 0.022 in round and rectangular forms. The smaller wires can be used as auxiliary springs for uprighting and rotations as well as aligning arches (Mollenhauer, 1987). (Fig. 3).

Soft stainless steel wires are used for ligating archwires into brackets and to maintain space closure following active mechanics. These wires are annealed to produce a dead soft wire and are available in diameters from 0.009 to 0.014 of an inch.

Braided Wires

A variety of different braided stainless steel wire is available. These are produced by either plaiting three elements together or by plaiting a small diameter wire around a single strand as a coaxial wire (Fig. 4). They are produced as round or rectangular wires and are indicated for early stages of treatment to align incisors either as single arches or in combination with heavier arches as they have a wide working range (Rock & Wilson 1988). These wires are easily distorted and have largely been replaced with the flexible nickel titanium wires. However they are a useful alternative where patients are sensitive to nickel (see allergies), and are considerably cheaper than nickel titanium wires.

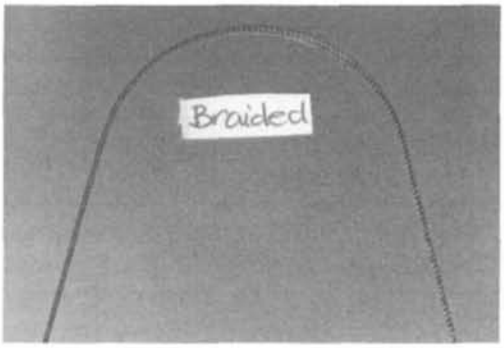


Fig. 4. Performed arch wire in braided stainless steel.

Titanium

Titanium is a light weight metal abundant in the earth's crust and at 4.5g/cm3 is considerably less dense than gold (19.3g/cm3), cobalt-chromium (8.5g/cm3) or stainless steel (7.9g/cm3) (Lautenschlager & Monaghan 1993). Titanium has excellent biocompatability and with its alloys has a very high resistance to corrosion due to a particularly adherent and inert oxide which forms rapidly on the surface.

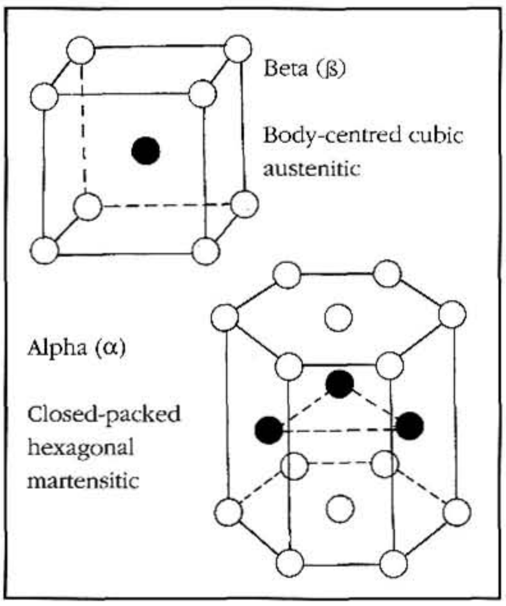


Fig. 5. Crystal structure of unalloyed titanium.

Pure titanium undergoes a transformation of crystal structure from close-packed hexagonal, alpha phase (α), to body-centred cubic, beta (ß) phase at 883°C and can be alloyed with a wide variety of elements to improve strength, creep resistance, weldability and formability (Fig. 5). Elements such as aluminium, gallium and tin stabilise the α phase while vanadium, molybdenum and chromium stabilise the ß phase. Pure titanium brackets are now available as a one piece construction and thus nickel and solder free. (Hamula *et al.*, 1996)

A number of terms are used to describe the range of titanium alloys in use today (Evans and Durning 1996).

'Stabilised' nickel titanium: The alloy has a fixed composition which is incapable of demonstrating changes in its crystal structure. Its elastic properties are the result of it inherently stable structure.

'Active' nickel titanium: The alloy has a fixed composition, but is capable of undergoing changes in its crystal structure when stress or temperature is applied.

'Active' austenitic: On application of stress, the nickel titanium demonstrates a change in crystal structure from austenitic to martensitic.

'Active' martensitic: On application of heat at the relevant transition temperature, the nickel titanium demonstrates a change in crystal structure form martensitic to austenitic.

Transition temperature: That temperature range over which the alloy structure changes from the martensitic to the austenitic phase.

Superelastic: A term confined to those materials demonstrating unique hysteresis curves under conditions of varying temperature or stress.

Thermodynamic: This refers to the ability of an archwire to return to its intended shape once heated through its transition temperature. To be of clinical value, thermodynamic archwires must have a transition range close to mouth temperature.

Shape memory: This indicates only that a material will return to its desired shape. In order for the term to have clinical meaning the means by which the material is able to demonstrate this effect needs to be specified, for example, thermodynamic shape memory, or superelastic shape memory.

Nickel Titanium

These alloys are an offshoot of the NASA space research programme (Nickel Titanium Naval Ordinance Laboratory) were introduced to orthodontic use in the 1970's (Andreasen and Hilleman 1971). Nitinol is a stabilised nickel titanium formed by cold working to produce a martensitic crystal structure. These wires have a low modulus of elasticity providing low force levels over a wide working range and are excellent as aligning wires (Kusy and Greenberg 1982) (Fig. 6).

Fig. 6. Nickel titanium wire showing extreme flexibility and wide working range.

Superelastic nickel titanium (active austenitic) wires were introduced in the 1980's (Burstone *et al.*, 1985, Miura *et al.*, 1986). These wires have excellent springback properties with constant force levels at increased deflection. This material is capable of phase transformation under stress. Such active austenitic wires do not undergo phase transformation at mouth temperature, instead their super-elasticity results from stress induction when engaged into a bracket. (Tanner and Waters 1994). Such stress to the austenitic body centred cubic structure will induce a change to the close packed hexagonal martensitic structure. On stress relief a reverse transformation will occur (Khier *et al.*, 1991).

Thermodynamic, active martensitic alloys: Variations in heat treatment by the manufacture will change the stress levels required to initiate a phase transformation. The percentage of austenite at room temperature will vary the force delivery characteristic at mouth temperature. Transition temperatures can be set at mouth temperatures by the manufacturer, to convert from martensitic to austenitic phases. Martensitic alloy has a greater working range than austensite and is preferred when aligning (Evans and Durning 1996). One can vary the forces as required while maintaining constant wire dimensions.

Coil Springs

Nickel titanium open coil springs produce light, continuous forces through a long range of activation slightly below 75-100gms range. Closed coil Niti springs produce light continuous force within 75-100gms. These springs deliver a relatively constant force range of 7mm tooth movement with one activation and are excellent for space closing. (Von Fraunhofer *et al.*, 1993)

Copper Nickel Titanium

Copper Nickel Titanium is a quaternary (nickel titanium, copper and chromium) alloy (Ormco, Glendora USA). It is more resistant to deformation as a result of both temperature and mechanical insults. They are produced in four types according to the austenitic finish temperature.

Type I	15°C
Type II	27°C
Type III	35°C
Type IV	40°C

Copper enhances the thermal reactive properties of nickel titanium and demonstrates lower force values for the same degree of deflection than Niti wires. This allows earlier engagement of wires into brackets while still providing a long term relatively constant force.

Type I will produce a greater force while type IV will only provide an intermittent force each time mouth temperature reaches 40°C.

Beta-Titanium - (Titanium Molybdenum)

A beta titanium orthodontic wire alloy, TMA (Ormco/Sybron) (titanium-molybdenum alloy) has the nominal composition of 79% titanium, 11% molybdenum, 6% zirconium, and 4% tin (see Table 2). The addition of these alloying elements to pure titanium causes the body-centred cubic ß phase to be stable at room temperature, rather than the close-packed hexagonal α phase. TMA wires have excellent formability or the capability for permanent deformation. The ß titanium wire alloy has approximately one half the elastic force delivery of stainless steel wires with a yield strength ranging from about 100 000 to 140 000 psi (690 to 970 MPa). The elastic springback of elasticity for beta titanium (0.010 to 0.016) is significantly greater than for stainless steel wires (0.006 to 0.010).

A beta-titanium wire can therefore be deflected almost twice as much as stainless steel wire without permanent deformation. Beta-titanium wires also deliver about half the amount of force as do comparable stainless steel wires and has the added advantage of full bracket engagement and a resultant greater torque control than the smaller stainless steel wire. However beta-titanium experiences greater creep than stainless steel or Niti wires.

It is possible to attach stops, hooks and active auxiliaries by welding to beta-titanium wires, thereby increasing the versatility of the wire. However, adequate strength of the weld without loss in wire properties is achieved within a narrow optimal voltage setting on a resistance spot welder. A flat-to-flat electrode configuration is recommended for welding distortion. Overheating of the wire causes it to become brittle.

Beta-titanium wires demonstrate higher levels of bracket/wire friction than either stainless steel or Co-Cr wires. This may imply slower rates of tooth movement during canine retraction and space consolidation with beta-titanium wires than with stainless steel or Co-Cr wires.

Alpha Titanium (Titanium, Aluminium, Vanadium)

Alpha titanium has the nominal composition of 90% titanium, 6% aluminium and 4% vanadium (Table 2). At room temperature this composition supports a mixture of α and ß phases. Therefore their structure is a mixture of close-packed hexagonal (α phase) and body centred cubic (ß phase). (Lautenschlager and Monaghan 1993). These alloys are more brittle than TMA wires but still can be formed into loops and bends with care. Pliers with flat polished beaks are recommended which do not score the wire and contribute to a brittle fracture.

The elastic properties of these alloys are comparable to gold but half that of Co-Cr or stainless steel. Tensile strength is half that of stainless steel but ductility is considerably less. Coincident with low ductility is low creep.These alloys absorb hydrogen more readily than ß titanium and will saturate at a lower temperature in a moist environment. Clinical observation has shown this to improve strength and resilience in the mouth while making them more brittle. These wires are produced by AJ Wilcock in various sizes and preformed arches and can be used as finishing wires. Both α and ß titanium wires are nickel free and can be used where patients report nickel sensitivity.

Cobalt-chromium-nickel

The cobalt-chromium-nickel orthodontic wires are very similar in appearance, physical properties and joining characteristics to the stainless steel wires, yet have a much different composition and considerably greater heat treatment response. The most commonly used, Elgiloy (Rocky Mountain Orthodontics), has a nominal composition of 40% cobalt, 20% chromium, 15% nickel, 15.8% iron, 7% molybdenum, 2% manganese, 0.15% carbon, and 0.04% beryllium (see Table 2), which is somewhat similar to that for partial denture casting alloys. (Filmore and Tomlinson 1979)

Elgiloy can be shaped with pliers before heat treatment however, careful manipulation is required. The most resilient Elgiloy is marked red and provides high spring qualities. Since this wire fractures easily after heat treatment, all adjustment should be made before this precipitation hardening process.

With the exception of red temper Elgiloy, nonheat-treated Co-Cr wires have a smaller springback than stainless steel wires of comparable sizes, but this property can be improved by adequate heat treatment. The ideal temperature for heat treatment is 900° F (482° C) or 7 to 12 minutes in dental furnace. This causes precipitation-hardening of the alloy, increasing resistance of the wire to deformation and results in a wire that demonstrates properties similar to those of stainless steel. Heat treatment at temperatures about 1200° F (749° C) results in a rapid decline in resistance to deformation because of partial annealing. Optimum levels of heat treatment are confirmed by a dark straw-coloured wire or by use of temperature-indicating paste.

The advantages of Co-Cr wires over stainless steel wires include greater resistance to fatigue and distortion, and longer function as a resilient spring. In most other respects, the mechanical properties of Co-Cr wires are very similar to those of stainless steel wires. Therefore, stainless steel wires may be used instead of Co-Cr wires of the same size in clinical situations in which heat-hardening capability and added torsional strength of Co-Cr wires are not required.

The high moduli of elasticity of Co-Cr and stainless steel wires suggest that these wires deliver twice the force of beta-titanium wires and four times the force of nickel titanium wires for equal amount activation. The resultant undesired force vectors are therefore greater with Co-Cr and stainless steel wires than with both types of titanium alloys. Clinically, this may translate into faster rates of mesial movement of posterior teeth, thus placing greater demands on intra and extraoral anchorage.

Friction

The frictional forces created between a bracket and a wire is dependent on the coefficient of friction and the load between the wire and the bracket (Jarabak and Fizzell 1963). Such a loading can be from binding of the wire in a vertical or horizontal plane

when unravelling crowding. The arch length of a wire is at its maximum when all teeth are engaged directly into brackets. As the teeth unravel into the ideal arch, the arch wire will need to slide through the brackets and molar tubes as the wire length decreases from molar to molar. The more flexible the wire, the earlier brackets can be engaged completely, however, the unloading forces generates greater friction and therefore slows down treatment (Meling *et al.*, 1997). The operator has control in reducing such frictional forces by:

- reducing the number of brackets engaged
- reducing the deflection of the archwire hence unloading force
- bracket/ tube design
- bracket material
- archwire size
- archwire alloy
- fastening system between archwire and bracket.

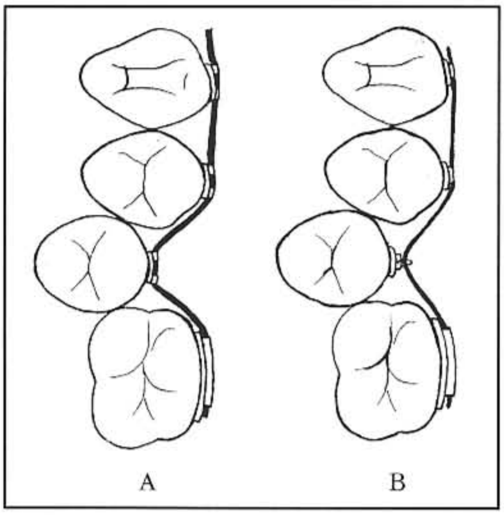


Fig. 7. A - Flexible wire in a horizontal slot: binding at each end will increase friction.

B - Single point contact of wire and bracket either by bracket design or ligature tie through a vertical slot will reduce friction.

A horizontal slot will always bind at each end to increase friction. Single point brackets will reduce friction as there is no binding on unloading which will limit free sliding as the arch wire shortens (Fig. 7). Horizontal slot brackets have more recently been modified to open the entry and exit dimensions thus reducing binding in levelling.

The same principles apply to allow archwires to slide through molar tubes. Tube diameter and length will determine the friction of components between the tube and arch wire.

Vertical slot brackets can be fastened with pins or ligature wires and horizontal slot brackets, elastomeric modules or ligature wires. Pins and loose ligatures provide less friction between the bracket and archwires. Elastomeric modules have been shown to create friction equal to 50gm tensile force. Therefore they should not be used with flexible wires where tooth movements require the wire to slide through the bracket (Meling *et al.*, 1997) such as during initial unravelling of crowding. Self ligating brackets such as the Speed brackets show reduced friction over conventional ligating systems (Berger 1990).

Table 3 Conversion of Wire Diameters

Millimetres	Inches
1.25	0.049
1.0	0.039
0.9	0.035
0.8	0.032
0.7	0.028
0.65	0.026
0.6	0.024
0.55	0.022
0.5	0.020
0.45	0.018
0.4	0.016
0.35	0.014
0.3	0.012
0.25	0.010

AESTHETIC BRACKETS

A variety of brackets which are more aesthetic is now available. The first were acrylic (plastic) brackets which had little success due to their water absorption and plastic deformation under load. They also stained very easily, eliminating any aesthetic advantage. Polycarbonate brackets are still not rigid enough to resist torque pressures and are more brittle and prone to fracture.

Ceramic Brackets

Ceramic brackets were introduced in the 1980's as an aesthetic bracket in an effort to overcome the disadvantages of plastic. Ceramic brackets are composed of either aluminium oxide or partially stabilised zirconium. There are two types of aluminium oxide ceramic brackets, monocrystalline or polycrystalline.

Monocrystalline ceramic brackets are clearer than polycrystalline brackets which are translucent. Monocrystalline brackets are manufactured by heating aluminium oxide to above 2100°C. The molten mass is cooled slowly and the bracket machined from the resulting crystal (Bordeaux *et al.*, 1994).

Polycrystalline brackets are made by mixing aluminium particles then injecting them into moulds. The binder is burnt out at 1800°C leaving aluminium oxide. The brackets are then machined and heat treated to relieve surface stresses (Swartz 1988). Polycrystalline brackets are less expensive to produce, however due to their crystalline nature, imperfections in the grain boundaries can lead to crack propagation and fracture. These grain boundaries are also responsible for the translucency of the bracket rather than a clear single crystal (Fig. 8).

The strength characteristics of these brackets depends on the condition of the surface of the ceramic. Scratches in the surfaces will facilitate crack propagation and reduce the forces required to fracture. This is particularly important when engaging ligatures into ceramic tie wings. Worn poly crystalline ceramic brackets will be more prone to fracture (Gibb 1992).

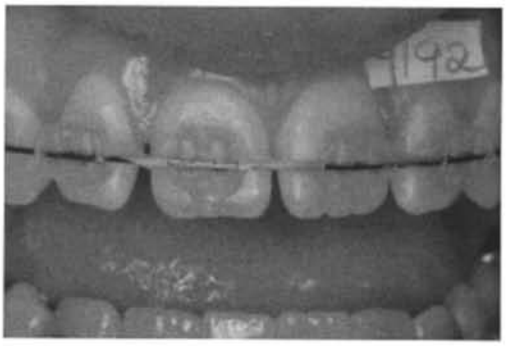


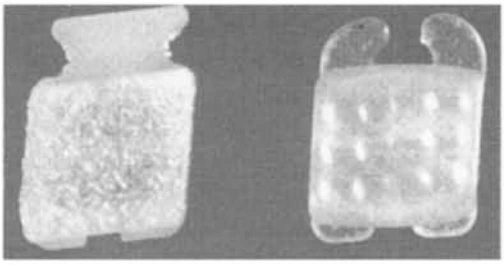
Fig. 8. Alumina ceramic brackets

Zirconium is extracted from beach sand is a highly stress resistant material. Brackets made from this material are more opaque than polycrystalline aluminium oxide. Zirconium has the unique property of improved inherent strength with wear and is thus less prone to fracture under loading (Kittibul and Godfrey 1995). Ceramic brackets are durable and they are resistant to discolouration. However the added bulk required to provide adequate strength with aluminium oxide ceramics, makes oral hygiene more difficult (Karamouzos *et al.*, 1997).

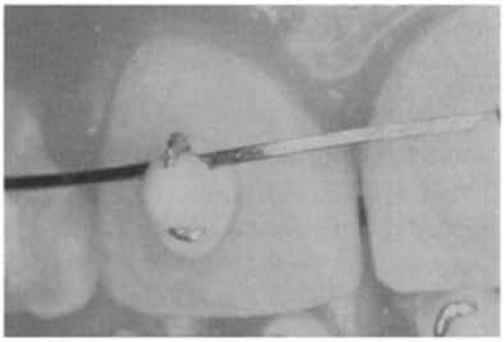
Bonding Ceramic Brackets

The early ceramic brackets with chemically bonded to composite resins by means of a silane coating on the base of the bracket (Guess *et al.*, 1988). This bond is extremely strong and has the potential for damaging the enamel surface during debonding as the silane bond is greater than that of the enamel composite bond (Odegaard 1989, Joseph &

Russoux 1990). This is of particular concern when bonding heavily restored teeth or non vital teeth with brittle enamel. An alternative design of bracket base incorporates a mechanical lock between the bracket base and the composite resin (Fig. 9A). This reduces the strength between the adhesive and the bracket base. Shear loading of the mechanically retained ceramic brackets results in cohesive failure of the adhesive leaving materials both at the enamel and bracket surfaces with less risk of enamel fracture (Carty and Tyas 1993). An alternative design of bracket to reduce enamel fracture is to place a plastic wafer between the adhesive and the bracket base. The weak link in the system is the bond between the wafer and the bracket base so that on debonding the brackets comes away leaving the wafer and composite resin on the tooth surface (Bordeaux *et al.*, 1994).



A



B

Fig. 9. A - Mechanical locking bases for ceramic brackets.
B - Zirconium ceramic bracket (Courtesy Dr Brian Lee).

Bracket Fracture

Aluminium oxide ceramics have a lower fracture toughness and this is a particular concern when engaging tie wings in edgewise/straight wire brackets. The ability to resist fracture is dependent on the bulk of material in the wing area. (Swartz 1988, Kusy 1988, Scott 1988, Viazis *et al.*, 1990, Birnie 1990). Particular care must be taken when using stainless steel ligatures, not to tie them tightly. Scratches in the ceramic will increase the risk of fracture. Zirconium brackets have a greater fracture toughness and are more resistant to fracture (Fig. 9B).

DEBONDING TECHNIQUES

Ceramic brackets are very brittle and will not flex like metal brackets when squeezed with debonding pliers or ligature cutters. Debonding metal brackets usually results in failure of the adhesive at the bracket/adhesive interface. Ceramic brackets have a higher bond strength and there is a shift in the site of failure to the enamel adhesive interface (Odegaard & Segner 1988, Britton *et al.*, 1990).

Mechanical Debonding

Mechanical debonding is aimed at applying a tensile or shear force to the bracket. Various manufacturers have produced special pliers for debonding their own brackets. The site of separation between bracket and adhesive is dependent on the type of adhesive used. Brackets bonded with lightly filled composite resins tended to separate at the adhesive bracket interface while brackets bonded with heavily filled resin separated at the adhesive enamel interface (Winchester 1992). An alternative technique is to use ligature cutters. The beaks are engaged at the adhesive enamel interface and the bracket debonded with a peeling action.

There is no significant difference between these two techniques and the incidence of enamel fractures, although there is a high incidence of tie wing fracture when debonding ceramic brackets with ligature cutters (Amditis 1994). There is a risk to the patient of aspiration of bracket fragments due to the sudden nature of bracket fracture. The removal of ceramic remnants from the enamel must be removed with high speed diamonds producing ceramic dust. Care must be taken to avoid skin and eye irritation (Winchester 1992, Bishara and Trulove 1990)

Lasers

The use of lasers for debonding ceramic brackets has been investigated (Strobl *et al.*, 1992, Tocchio *et al.*, 1993). The ceramic brackets were debonded by irradiating the labial surfaces of the brackets with laser light. The proposed laser-aided debonding technique was found to significantly reduce the residual debonding force, the risk of enamel damage, and the incidence of failure, as compared with the conventional methods. This technique has the potential to be less traumatic and painful for the patient and less risky for enamel damage (Strobl *et al.*, 1992, Tocchio *et al.*, 1993).

Thermodebonding

Localised heating of ceramic brackets past the plastification temperature will reduce the intermolecular binding forces of the adhesive resin adjacent to the ceramic base (Stratmann *et al.*, 1996). The ceramic debonding unit applies heat to the bracket while a torsional force is applied and there is little risk of damage to the pulp or enamel where forces are kept below 80nm.

The time taken to reach maximum pulpal wall and buccal surface temperatures decreases as torsional forces increase. This will also increase as the thickness of the resin increases. The site of bond failure with thermal debonding is either at the bracket resin interface or within the resin (Crooks *et al.*, 1997).

Torsional forces between 40 to 80Nm usually produce a pulpal temperature change less than 5.5°C considered the critical temperature for irreversible pulp damage (Bazner *et al.*, 1991, Ruppenthal and Baumann 1992).

More recently ceramic brackets have been designed with both a mechanical lock base and a vertical slot. Debonding such a bracket by squeezing it along its long axis will split the bracket with little risk of enamel fracture. Separation is at the bracket adhesive interface (Bishara *et al.*, 1997).

Enamel Wear

Ceramics are extremely hard with a hardness seven times greater than tooth enamel (Kusy 1988). Enamel wear on cusps opposing ceramic brackets can occur very quickly and brackets should not be placed in areas of occlusal interferences. As a general rule, ceramic brackets should be restricted to the maxillary anterior teeth. The patient should be informed of the potential disadvantages of such appliances and the risks that are to be undertaken.(Viazis *et al.*, 1989, Ghafari 1992).

Friction

The coefficient of friction of ceramic brackets is greater than that of stainless steel. When using sliding mechanics of ceramic brackets over stainless steel wires there will be an increase in time taken to close spaces. (Alexander 1992, Tanne *et al.*, 1991, Tselepis *et al.*, 1994, Ireland *et al.*, 1991). Use of closing loops will avoid this problem but adds to the complexity of mechanics. Newer brackets have stainless steel inserts into the bracket slot to reduce friction and are preferred over the standard ceramic. Zirconium brackets offer no significant improvement over alumina brackets with regard to their frictional characteristics (Keith *et al.*, 1994).

ACID ETCH BONDING

The direct bonding of orthodontic attachments to teeth has become routine in fixed appliance therapy and has several advantages over banding.

- Aesthetics are improved;
- Bonding of attachments to multiple units is faster;
- The patient experiences less discomfort;
- Overall arch length is not increased;
- No interproximal spaces are created;
- Bracket placement is more precise;
- Oral hygiene is easier;
- Partially erupted teeth and teeth with poor or abnormal morphology can be bracketed;
- Access to mesial and distal enamel facilitates tooth build-up or modification;
- Separating elastics are not required.

However, it also has its disadvantages:

- Bonded attachments are weaker than cemented bands, increasing the chances of bracket failure under occlusal forces;
- Bonded attachments will not withstand some orthodontic forces such as extra-oral traction.

Average failure rates for bounded attachments are 5 or 6% (Miura *et al.*, 1974), although the rate will vary with the type of tooth: upper anterior teeth show the lowest failure rates, premolars are more likely to fail and failure rates are highest in molars. Decalcification around orthodontic attachments, leading to white spot lesions and even frank cavitation, remains a serious problem with acid etch bonding (Zachrisson 1977).

This technique was first described in 1955 by Buonocore, who acid-etched enamel using orthophosphoric acid to increase the bond strength of acrylic restorative resins (Buonocore 1955). Later on, Newman (1965) reported the successful use of an epoxy adhesive for bonding orthodontic brackets. At this time, etching for sixty seconds was recommended, however, further studies support the use of shorter etching times as etching times beyond 60 seconds will eliminate the protective surface fluorine and risks significant loss of the enamel surface(Sampson *et al.*, 1987). There are no significant morphological differences between enamel etched for 15 seconds and 60 seconds with phosphoric acid with no differences in bond strengths for composite resins bonded to enamel after etching for 15 seconds and 60 seconds. A 15 second etch time is now generally accepted. However, the critical etch time depends on the quality of the enamel to be etched. In older teeth, and in teeth with substantial fluoroapatite components, etch times may need to be increased or etching repeated before the characteristic whitish or chalky appearance of properly etched enamel is obtained (Marzouk *et al.*, 1986).

During clinical bonding, complete removal of etchants and their reaction products (dissolved calcium phosphates) and the preservation of a dry, etched, bonding site is essential for the longevity of the enamel bond (Tagami *et al.*, 1988). Washing times should be 10 to 15 seconds (Williams & Von Fraunhofer 1977) however, this should be increased for acid gels since their cellulose vehicle may serve as a contaminant (Gwinnett 1976). A prolonged, 60-second rinse with a water-air spray may damage the delicate etched enamel resulting in a significantly weaker bond (Mixson *et al.*, 1988).

Composite Bonding Materials

Almost all of the orthodontic adhesives currently used are based on the bis-GMA formula, with diluent monomers added to lower viscosity and improve handling. Until recently ordinary restorative two-paste bis-GMA composites were widely used; their viscosity could be reduced by diluting both pastes with liquid sealant resins (Artun and Zachrisson 1982). The adhesives contain inorganic filler particles (up to 70% by volume) to increase viscosity, reduce polymerisation shrinkage, allow thermal dimensional change of the set composite to approximate those of enamel and increase strength and wear resistance. The filler content of orthodontic composites is lower than that used in restorative resins, primarily to allow easier removal of the adhesive at debonding.

Chemically Cured Composites

Chemically cured orthodontic composites are available in either two-paste or no-mix systems.

Two-paste composites

Two-paste composites give the strongest bond which is their greatest advantage (Delport and Grobler 1988) and are particularly indicated for posterior teeth. The composite cures when the two pastes are mixed together. They tend to have a 'tacky' viscosity, which reduces slippage of a bracket placed on a tooth. The two-paste system have a short working time, one needs to prepare separate mixes for each bracket or group of brackets. Two paste systems have greater problems with oral hygiene as the flash is difficult to remove prior to setting without moving the bracket. Excess flash will set hard and then requires rotary instruments to polish it from the bracket margin.

No-mix composites

No-mix composites are supplied composite paste and a liquid primer. A thin coat of primer is painted onto the bracket base and the etched enamel surface, after which the bracket base is loaded with composite. No-mix systems have the advantages of less waste, easier debonding and a longer working time. They are, however, less viscous, allowing bracket drift. As the bracket is pressed onto the enamel surface, the resin is activated from both sides. Excess flash is essentially unreacted paste and easily removed as it does not set thus improving oral hygiene.

Light Cured Composites

The advantage of light-cured orthodontic composites over chemically cured composites is that a 'command set'allows the operator almost unlimited working time for bracket placement. After cleaning and etching, the brackets are placed on the teeth and can be positioned accurately before curing. It is possible to reposition the brackets and remove excess composite following seating. Once the positioning is satisfactory the brackets are cured in turn for 20 to 30 seconds, directing the light source down the long axis of each tooth, both from the occlusal and gingival directions. Transillumination will cure the composite under metal brackets.

Bond strengths for light-cured materials are reported to be comparable *in vitro* to those of chemically cured composites (Tavas and Watts 1979, 1984), but the material is not quite as reliable *in vivo*. The bond strength can be increased to that of the chemically cured composites by precuring the bracket base with a low-viscosity resin. Light-cured composites are particularly useful in situations where increased working time is required, such as

when placing bonded lingual retainers or lingual attachments. With any light curing it is important to check the power of the light source. Light guns should be tested regularly to verify a complete set of the composite.

Precoated Brackets

A recent innovation is to use bracket precoated with light-cured composite and stored in suitable containers (Tavas and Watts 1984). This has several possible advantages:

- consistent quality and quantity of adhesive;
- reduced flash during bonding;
- reduced waste during bonding; and
- improved cross infection control (Cooper *et al.*, 1992)

Adhesive precoated metallic brackets appear to have a bond strength similar to that of non-precoated metallic brackets. Precoated ceramic brackets possess a slightly lower, but still acceptable, bond strength.

DEBONDING COMPOSITE RESINS

Several authors have advocated the use of unfilled or lightly filled, rather than filled, adhesives for bonding (Gwinnett and Gorelick, 1977, Retief and Denys 1979).

Filled adhesives provide a stronger bond but attract and retain plaque, predisposing to poor gingival health and decalcification around bracket margins. Therefore excess adhesive around the brackets should be removed at the bonding stage and at bands off, the adhesive should be completely removed. Composite resins do not abrade over time and retained adhesive may lead to discolouration, accumulation of plaque and decalcification (Brobakken and Zachrisson 1981). At debond, filled adhesives may fail at the adhesive/ enamel interface, which may cause fractures in the enamel. When debonding, unfilled adhesives are more likely to produce cohesive failure within the adhesive rather than at the adhesive/enamel interface reducing the risk of enamel fracture. Unfilled adhesives accumulate less plaque during treatment, however, adhesives containing submicron fillers are more difficult to distinguish from enamel than those with coarser filler particles.

Hand Instruments

The use of hand instruments such as scalers for removal of adhesive is contra-indicated because these instruments produce 'tear outs' (Zachrisson, 1985), prominent grooves and gouges in the enamel surface (Gwinnett and Gorelick, 1977). Hand instruments also leave more adhesive remaining on the teeth than other methods.

Rotary Instruments

The means of adhesive removal which leaves the most acceptable enamel finish is to use a plain cut or spiral fluted tungsten carbide bur (Hannah and Smith, 1973) in a contra-angle handpiece followed by a final polish using pumice and a rubber cup (Howell and Weekes 1990). The bur should be used at a slow speed (Between 20000 and 30000 r.p.m.) and with a gentle brushing motion across the enamel surface. It may be run at higher speeds through bulky composite, but not at the enamel surface in case unwanted damage is caused.

The shape or cut of the bur has little effect on its efficacy, but for bulk composite removal a larger diameter bur is preferable.

Diamond Burs

Of all the instruments tested, diamond burs (even superfine) are the ***least*** acceptable because they cause excessive enamel loss and roughening of the surface (Zachrisson and Artun, 1979).

Enamel Loss

An average of 55.6μm enamel is lost from the tooth surface as a result of the whole process of bonding and debonding (Fitzpatrick and Way 1977). The thickness of enamel on the buccal surface of a premolar tooth is between 1500 and 2000μm, so this is not a great deal to lose except that only the outer 20μm is rich in fluoride. At layers deeper than this the fluoride concentration rapidly decreases (Brown and Way 1978). This layer should be preserved if possible, although enamel morphology returns to normal within 3 to 6 months of debonding (Newmann 1969).

GLASS-IONOMER CEMENTS

The glass ionomer cements were formulated by Wilson and Kent (1971) and introduced into Australia by McLean and Wilson (1977). A version for luting was developed by Wilson *et al.*, (1977). These cements are truly adhesive to enamel and dentine and are amongst the least irritant of all cements since they contain preformed polymers rather than monomers. (Wilson and Prosser 1982).

The glass ionomer cement system consists of the following (Crisp *et al.*, 1975):

1. Poly alkenoic acid, commonly a homo- or co-polymer of acrylic acid.
2. An ion leachable alumina silicate glass to provide ions to cross link the chains.
3. Water as a reaction medium.
4. Tartaric acid to improve working and setting characteristics.

They are essentially a powder liquid cement with an alumino silicate glass of high fluoride content, forming the basis of the powder. The conventional cement has a clear viscous liquid, containing a 50 percent aqueous solution of copolymer of polyacrylic and itaconic acid with tartaric acid as a hardening agent.

The glass ionomer cements have the following characteristics(Wilson and Prosser 1982);

1. Rapid set. (4-5 mins.)
2. Low temperature rise during setting.
3. High compressive strength. (140-200 Mpa after 24 hours)
4. Translucency similar to tooth enamel.
5. Adhesion to enamel, dentine and base metals.
6. Resistance to acid erosion.
7. Long term fluoride release.

Glass ionomer is formed by an acid base setting reaction between alumino silicate glass and poly-acid. Protons from the acid penetrate the glass powder to release calcium and aluminium ions, initiating a prolonged, two phase setting reaction. Calcium ions bind to the polyacrylic acid producing gelation and the initial adhesion to tooth structure. Aluminium ions then contribute to the subsequent hardening stage as more rigid cross linking occurs forming aluminium polycarboxylates. It is during the first phase while calcium salts predominate, that the glass ionomers are extremely sensitive to moisture contamination and dehydration. (Swift 1986).

The second generation water hardening cements contain the same acids in freeze dried powder form or an alternative powdered co-polymer of acrylic and maleic acids. These dried powders are supplied blended with the glass powder and require only distilled water as the liquid. (Prosser *et al.*, 1984).

More recently the glass-ionomer cements have been modified to produce dual cure cements or hybrid cements. These set partly via an acid-base reaction and partly via a photochemical polymerisation (Bourke *et al.*, 1992). Other modifications have included dual cured resin based adhesives containing fluoro-alumino glass (McLean *et al.*, 1994).

A true glass-ionomer cement requires that the acid base reaction contribute to the setting process - a process which continues in the absence of light. Hybrid cements which are initiated with visible light produce higher initial bond strengths than chemically cured cements (Comptom *et al.*, 1992).

Resin-modified glass-ionomer cements can be used to bond to enamel that is resistant to acid etch (such as teeth which have had prolonged exposure to fluoride) and to composite-resin crown build-ups. Clinical observations have shown that these cements also perform satisfactorily in cases of *amelogenesis imperfecta* (Fricker 1996) (*Fig.10*).

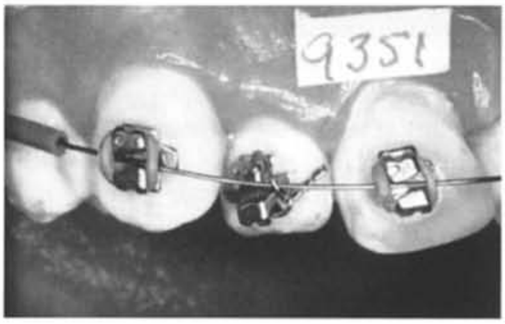


Fig. 10. Teeth with *amelogenesis imperfecta*. The central incisor has a composite veneer. Brackets bonded with resin - modified glass-ionomer cement.

Clinical procedures should be used which will encourage the development of an ion-enriched layer at the interface between the cement and the enamel. This is a most important factor in the retention properties of glass-ionomer cements and for the prevention of microleakage (Mount 1991). Polyacrylic ions attach to hydroxyapatite by displacing phosphate and calcium ions from its surface. The surface layer of the adhering cement becomes enriched in these ions as they diffuse from the enamel surface.

The ionic exchange between cement and enamel will occur more easily on a clean surface and in the absence of contaminants. Therefore, the enamel should be conditioned with 10 per cent polyacrylic acid for ten seconds, rinsed thoroughly and lightly dried prior to placing the cement (Aboush & Jenkins 1987) The strength of the adhesion is directly proportional to the tensile strength of the cement. Failure is cohesive within the cement and not at the interface with the enamel (Mount 1993).

The resin-modified light-activated glass-ionomer cements have the added advantage of being resistant to moisture uptake and dehydration as soon as they have been light-activated. The initial set of these material is the result of polymerisation of HEMA (Hydroxy Ethyl MethAcrylate). The acid base reaction of the glass-ionomer serves to harden and strengthen the polymer matrix (Wilson 1990). However, prior to activation with visible light, exposure to moisture will interfere with the setting of the ionomer components and the formation of the ion-enriched layer, thereby reducing the strength of the final set. Furthermore, as the resin component of these cements is strongly hydrophilic, excess water around the bracket during placement will cause an uptake of water into the structure of the cement. This will lead to greater plasticity and reduction in strength (Nicholson and McLean 1992).

Banding with Glass Ionomer Cements

Glass ionomer cements have the properties of physico-chemical bonding to enamel and to base metals and leach fluoride over the long term making them suitable as band cement. A number of clinical trials have shown these cements to be more effective than zinc phosphate cement in the retention of molar bands (Fricker and McLachlan 1985, 1987, Seeholzer Dasch 1986, Mizrahi 1988

and Stirrups 1991). The enamel adjacent to the cement takes up substantial amounts of fluoride (Swartz *et al.*, 1984) and there is less decalcification around band margins compared with bands cemented with zinc phosphate (Fricker and McLachlan 1987).

The clinical technique is critical to maximise the retention of orthodontic bands. Variation in powder liquid ratios have a significant influence on physical properties where a thicker mix increases the bond strength to enamel and thinner mixes reduce the strength (Wong and Bryant 1985). Powder liquid ratios as recommended by the manufacturer should always be followed.

Glass ionomer cements should be mixed on a chilled glass slab and surface dew should be wiped off prior to dispensing the powder and liquid. Cooling the mix will allow easier incorporation of powder into the liquid with an increase in the working time out of the mouth and a comparatively rapid set in the mouth (Fricker *et al.*, 1991). Glass ionomer cements are now available in capsules and these are mixed in a silamat (or equivalent) for 10 seconds and extruded from the capsule with special pliers (Fig. 11).

Teeth for cementation should be cleaned and isolated from excess moisture with cotton rolls. Mixed cement is placed in the band and the band seated on the tooth. Working time is limited by the gelling of the mixed cement as once this is reached, the cement will not adequately wet the surface of the enamel and bond strength is reduced. Capsulated cements will have a reduced working time due to their lacking of chilling during mixing.

Once the band is cemented, the margins must be protected from moisture as early contamination will reduce the strength of the material and leave the margins of the band more susceptible to erosion. A simple method of protection is to cover the bands with a generous layer of Vaseline petroleum jelly (Earl *et al.*, 1985).

Resin modified glass ionomers are also appropriate for cementation of orthodontic bands (Fricker 1997) and are available as self cure cements or light activated. The technique for self cure resin modified cements is the same as standard glass-ionomer and requires protection from moisture while setting. Light activated adhesives do not require protection from moisture, once cured for 20 seconds around the margins the patient can rinse out straight away.

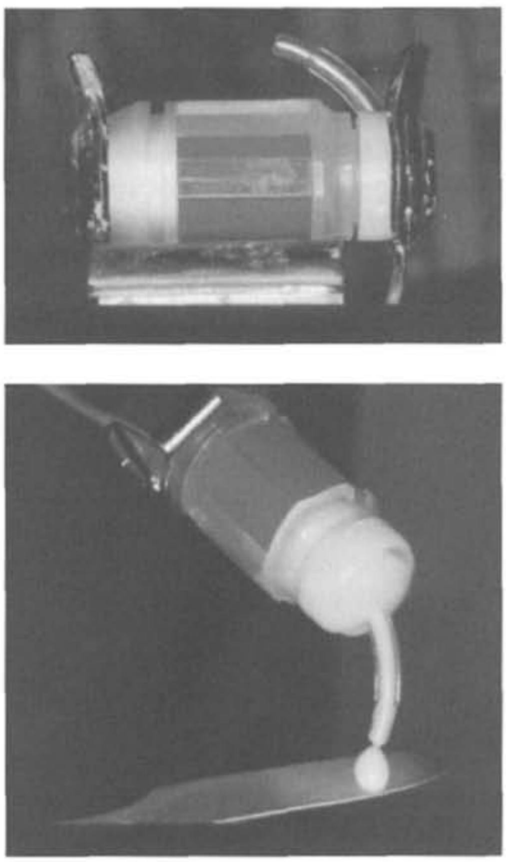


Fig. 11. Ketac-Cem Capsules (Espe).

Cementation with Glass Ionomer Cement

1. Thoroughly clean the surface of the tooth
2. Isolate with cotton rolls
3. Mix glass ionomer cement on a chilled glass slab in manufacturers recommended proportions
4. Place inside the band, two bands per mix
5. Fit to tooth and extrude excess
6. For light cure, cure for 20 seconds - for self cure, cover with a generous layer of vaseline.
7. Allow 30 minutes before engaging archwires.

Bonding with Glass Ionomer Cements

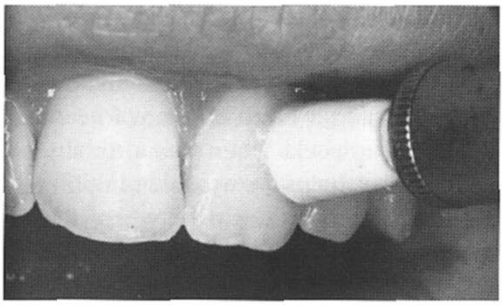
The standard glass ionomer cements showed some promise for the direct bonding of metal brackets but the failure rates when compared with composite resins were not clinically acceptable (Fricker 1992). However, the retention rates of brackets bonded with resin-modified glass-ionomers are as good as composite resins if occlusal interferences are avoided (Fricker 1994). Furthermore, there is no significant difference between self cured and light cured cements (Fricker 1994, 1997).

The distinction should be made between the conditioning action of 10% polyacrylic acid and the etching of 37% phosphoric acid. Polyacrylic acid will remove surface contaminants at the same time reducing the surface energy. The highly mineralised enamel surface is then exposed to the diffusion of acids in the cement and the exchange of ions (Mount 1994). Such conditioning improve the bond strength on the glass-ionomer cement to enamel (Attin *et al.*, 1996, Jobalia *et al.*, 1997).

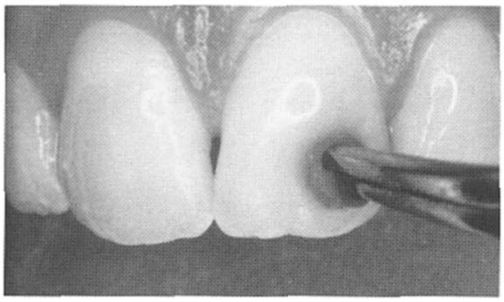
Etching the enamel with 37% phosphoric acid produces channels 10 to 30mm deep. Resin flows into these channels by capillary action then hardens. The bonding mechanism of resin to etched enamel is micro-mechanical bonding (O'Brien 1989).

Bonding with Resin-Modified Glass Ionomer Cement

1. Clean enamel surfaces of teeth to be bonded with a rubber cup or brush and a slurry of pumice and water (Fig 12a)
2. Rinse thoroughly with water.
3. Place cheek and tongue retractors as required for a clear view.
4. Condition the enamel with polyacrylic acid for 10 seconds each tooth (Fig 12b).
5. Rinse thoroughly and remove excess water with an oil-free air syringe.
6. Mix powder and liquid on a chilled glass slab according to manufacturer's instructions.
7. Coat the base of the bracket with a small amount of paste and press firmly onto the tooth surface.
8. Place three brackets with each mix and remove the excess flash as the cement starts to gel. Take care not to move the bracket.
9. Light-activate each bracket from the incisal, gingival and lingual for 20 seconds each direction.
10. For self cure cement, allow to set for four minutes before rinsing out (Fig 12c).
11. Allow 15 minutes before engaging archwire.



A



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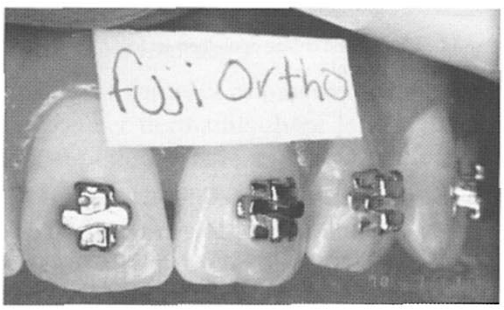

C

Fig. 12. A - Clean enamel surface with a slurry of pumice and water and rinse off with oil free water.

B - Condition the surface of the enamel with 10% polyacrylic acid for ten seconds, rinse off with water and remove excess moisture.

C - Self cure - resin-modified glass--ionomer cement. Allow at least 4 minutes to set before allowing the patient to rinse.

Debonding Glass Ionomer Cement

The difference in adhesive mechanisms between glass-ionomer cements and composite resin is important when debonding brackets. The bond strength of glass-ionomer cement is greater to tooth enamel than to metal (Fricker and Kameda 1990) so that, once the bracket is removed, the bulk of the adhesive remains on the tooth surface. Removal of the adhesive with an ultrasonic cleaner minimises the risk of mechanical damage to the enamel. In order to provide a smooth surface, final prophylaxis of the enamel surface should be carried out with a slurry of pumice and water; as described by Howell and Weekes (1990).

1. With bracket removing pliers, squeeze the bracket mesio-distally to flex the base. The adhesive will fracture at the adhesive bracket interface, leaving the bulk of the adhesive on the tooth surface (Fig 13).
2. Use an ultra-sonic scaler to remove the remaining adhesive from the enamel.
3. Smooth and polish with a slurry of pumice and water.

Fig. 13. Resin modified glass-ionomer cement, at bands off, cement remains at the enamel interface.

ELASTICS

Orthodontic elastomeric materials provide an essential component in the mechanism of moving teeth. Standard elastic bands are available in a range of dimensions reflecting a variety of force values. Such elastics are used for inter-arch mechanics to correct Class II overjets, Class III cross bites and buccal open bites. Intra-arch mechanics utilise elastic to close extraction spaces through sliding mechanics.

Physiological tooth movement relies on the use of light forces (Chapter 15) and the selection of force value of an elastic is balanced by anchorage requirements, torque values and the friction within the appliance that needs to be overcome. Force values for tooth movement should not exceed 100mg and this can be tested in the mouth with a tension gauge.

Elastics should be changed every four to five days (or when they break) so as to maintain a light pressure to the teeth.

Elastomeric Chains

Elastics in the form of chains may be closed loop or open loop depending on the size of the link between each circle of elastic (Fig. 14). Closed loop chains have higher force values when stretched than open loop (DeGenova *et al.*, 1985). Chain elastics are particularly suitable for closing spaces and rotations of individual teeth by means of lingual and buccal attachments.

The longer the stretch of the chain the greater the initial force. This is combined with an increase in the rate of force decay (Lu *et al.*, 1995). Force values fall to approximately 50% of the original value after four weeks in the mouth (Rock *et al.*, 1985). Too much initial force will cause discomfort and risk root resorption (Begg and Kesling 1977). Most force decay occurs within the first hour (Lu *et al.*, 1993) and it is recommended that chain elastics be prestretched before placing them on the teeth to reduce the initial force and providing a more constant force over three to four weeks when they are changed. Elastomeric chains are available in different colours, variations occur between colours from a single manufacturer and similar colours from different manufacturers (Baty *et al.*, 1994). It is wise to test the force levels prior to engaging the teeth.

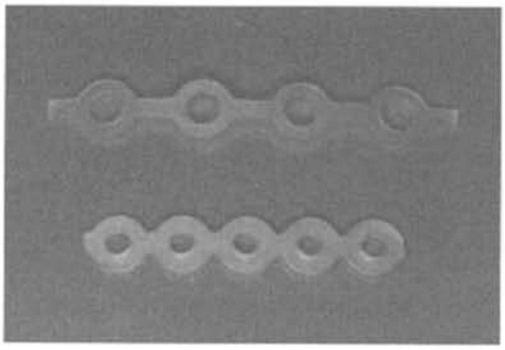

Fig. 14. Elastomeric chains open loop (at top) closed loop (at bottom).

Modules - O Rings

Elastic modules are used to fasten brackets to archwires and are available in many colours. A small range of dimensions and thicknesses are available and selection is based on bracket size and the depth of the tie wings. Modules increase the friction in the appliance up to 50 mg per bracket and reduce the efficiency of initial alignment with flexible wires (Meling *et al.*, 1997). As with elastomeric chain, it is wise to prestretch the module prior to fastening an archwire into a bracket to reduce initial force levels and hence patient discomfort.

ALLERGIES TO DENTAL MATERIALS

Allergic hypersensitivity related to dentistry is acquired by exposure to specific dental material allergens and the altered capacity

of the patient to react when re-exposed to the allergen (William 1996). Allergic reactions associated with dental materials are generally delayed hypersensitive reactions that are usually not associated with circulating antibodies, because the causative agents attain their allergenic properties by combining with the mucosal tissues of the patient. The delayed hypersensitive reaction is not manifested clinically until several hours after exposure (Shafer *et al.*, 1983). A contact allergy in dentistry is the type of reaction in which a lesion of the skin or mucosa occurs at a localised site after repeated contact with the allergenic material (Shafer *et al.*, 1983). The ability to cause contact sensitivity appears to be related to the ability of the simple chemical allergen to bind to proteins, especially those of the epidermis (Turk 1972), and in dentistry, specifically the oral mucosa.

Contact dermatitis

Clinical features

As in all forms of cell-mediated immunity, in contact dermatitis there is a minimum latent period of at least 5 days between the first contact with the allergen and the ability to react at a distant site to further contact with a nonirritant concentration of the allergen. Reactions take between 24 and 48 hours to develop and, if severe, may last for 7 to 10 days (Turk 1972).

The oral manifestations, known as contact stomatitis or stomatitis venenata, include an inflamed and edematous mucosa, accompanied by a severe burning sensation. Small, transient vesicles may form, these rupture to form areas of erosion and ulceration. Erythema, papules, and edema are characteristic allergic manifestations and, in severe reactions, large weeping blisters may appear (Huget 1977). Stomatitis venenata occurs less frequently than allergic skin lesions. This can be ascribed to the diluting, digestive, and washing effects of saliva.

Although certain dental materials have been implicated as causes of contact stomatitis, the reported incidence is low. However, when an offending dental material sensitises an area of the mucosa, no matter how small the area, the individual may become sensitised (Huget 1977).

Treatment and prognosis

Several methods of treating allergies have been reported, including symptomatic treatment, desensitisation, and elimination of the allergen (Nakayama *et al.*, 1990). Because the mechanism of the allergic reaction is not yet fully understood, the recommended method of treatment for contact dermatitis or stomatitis is the discontinuation of all contact with the allergenic material. This usually results in prompt remission of all the lesions.

Nickel

Nickel is the most common contact allergen in dentistry (Staekjaer & Menn, 1990). About 10 % of females are sensitive to nickel and the majority become sensitised through jewellery (Burrows 1986). Only 1% to 2% of males are found to be nickel sensitive, indicating a striking sex difference (Jones *et al.*, 1986, Al-Waheidi, 1995). The signs and symptoms of nickel sensitivity given are manifested when nickel containing gold jewellery, such as watches, bracelets and particularly earrings, are worn. Metal frames in spectacles are also a source of sensitivity.

Clinical reactions to nickel include oedema of the lids, swollen and fissured lips, and chronic eczema of the cheeks and palms (Kelly & Rose 1983). Nickel dermatitis can lead to secondary sites such as the skin, eyelids, sides of the neck and face (Huget 1977).

In orthodontics, allergic reactions to nickel in cervical headgear (Greig 1983) as well as allergic reactions to orthodontic wires (Dunlap *et al.*, 1989) and nickel-titanium orthodontic wires, have been reported. However, a recent study did not find that nickel-sensitive persons are at greater risk of developing discomfort in the oral cavity when wearing an intraoral orthodontic appliance (Staekjaer & Menne 1990).

Despite the reported allergenicity of nickel, few cases of adverse reactions to nickel-containing dental prostheses have been reported. The evidence that nickel absorptions intraorally exacerbates existing dermatitis is also minimal. Furthermore, there is little evidence available to implicate nickel as playing any part in the rejection of nickel-containing prostheses, dental or orthopaedic (Wiltshire 1989), and it must be concluded that nickel materials are generally safe to use in dentistry.

Latex Sensitivity

A variety of rubber-containing devices has been implicated in the production of iatrogenic reactions in patients: (Burke and Wilson 1995)

- latex gloves
- condoms
- urinary catheters
- tourniquets
- wheelchair tyres
- adhesive tapes and bandages
- hot water bottles
- sheets and pillows
- dental rubber dam
- endotracheal tubes
- haemodialysis units
- electrocardiographic strips

It is therefore important that patients who have a latex allergy be identified, a careful history should be taken from every patient regarding contact with latex. Among questions that may be asked are those concerning itching, rash or rhinitis following contact with latex-containing objects. Additionally, an unexplained allergic or anaphylactic reaction during a medical procedure may indicate sensitisation. Health care workers should also be asked if they have suffered a reaction of any type to latex gloves. Suspect patients should be referred for further testing.

For those patients who are subsequently found to demonstrate an allergic response to latex, gloves made of vinyl may be appropriate, although some brands have demonstrated poor puncture resistance and high stiffness, or polyvinyl overgloves may be used. Recently introduced non-latex, non-vinyl gloves made from synthetic copolymers or styrene butadine block polymers (Tactylon, Smart Practice; Elastyren, Allerderm Labs) may also be of value. Furthermore, manufacturers should be encouraged to avoid the use of potentially irritant chemicals during manufacture of gloves because it has been considered that additives are the main allergens in rubber materials. The thiuram group, the mercaptobe-zothiazole group, and the carbamates are allergens in rubber accelerators, while amines are allergens commonly present as antioxidants. Natural and synthetic rubber polymers are rarely contact allergens, but natural rubber may cause contact urticaria with immediate wheal and flare reactions. However, proteins from natural latex appear to be the cause of the most serious type of allergic reactions. (Burke *et al.*, 1995)

Recommendations

Certain materials in dentistry will cause allergic hypersensitivity in patients (Huget 1977, Wiltshire 1989). It is advisable to ask patients questions concerning past hypersensitivity to

dental materials or following dental procedures. As part of the medical history, each patient should also be specifically asked whether a rash or eczema had ever developed following the wearing of earrings or jewellery, especially with pierced ears.

In most patients, there is no indication for patch testing. Routine use of such a test for all patients should be avoided, because the test procedure may in some cases provoke sensitisation of the patient (Yontcher *et al.*, 1986). The main indication for an epicutaneos test is the presence of local symptoms in the mouth close to a dental restoration or prosthetic or orthodontic appliance.

When skin symptoms are present, the patient should be referred to a dermatologist for consultation. Once a positive test has been confirmed, the offending materials should be withdrawn. Rapid remission of the symptoms will confirm the positive allergy test and the patient should be made aware of his or her allergic status and be advised to report it to future dental practitioners. A repeat test may be necessary for true confirmation of allergy, but because of ethical considerations, may not be clinically possible.

The dentist forms an important link in the differential diagnosis of allergy. All possible allergenic dental materials should be considered when a positive response to allergic tendencies is reported in the history taking.

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Appendix
Oral Hygiene Care

Liz Codina

INTRODUCTION

Plaque control is one of the most important parts of orthodontic treatment and yet one of the most difficult to achieve compliance. Plaque is an organic nitrogenous mass firmly attached to the tooth structure. It is composed primarily of bacteria, with extracellular dextrans, salivary glycoproteins and food debris. (Fricker, 1997) It is then very important that the orthodontic patient masters the art of toothbrushing and interdental cleaning. It is a difficult task and it is up to the orthodontist/dental hygienist to monitor and to tailor instructions to individual needs and motivations. The patient must learn to recognise the difference between a clean tooth vs a tooth with plaque to prevent such problems as decalcification, caries and gingival enlargement. (Chang *et al.*, 1997) (Fig. 1A & B) Dental check-ups with removal of plaque and calculus from pockets are essential during this time period.

A

B

Fig. 1. A - Enlarged gingival tissue due to poor oral hygiene during treatment.

B - Delcafication and gingivitis at band removal.

HOME CARE INSTRUCTIONS

It is essential that the patient has a systematic approach to cleaning so that all tooth surfaces are thoroughly cleaned and that the technique he/she uses does not injure tooth and gingival tissue. Teeth and appliances need to be brushed thoroughly after each meal. Extra care needs to be used on band and bracket areas. The orthodontist/ dental hygienist will recommend a specific type of toothbrush and interdental aid according to patient capabilities.

DISCLOSING TABLETS/SOLUTIONS

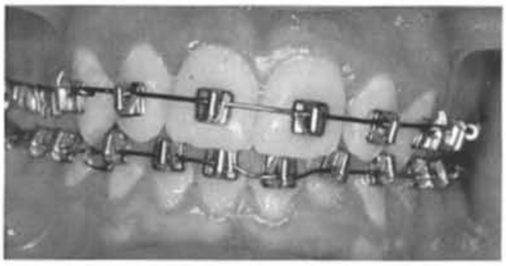
Plaque is normally tooth coloured and invisible to the naked eye. Disclosing tablets and liquid are a way for the patient to show plaque on his/her teeth and these are usually red in colour but other varieties are available e.g., Plak-lite used with a special light (Fig. 2).

Disclosing Tablets: Have the patient chew on tablet and swish around the mouth for 30 to 60 seconds. Rinse out with water.

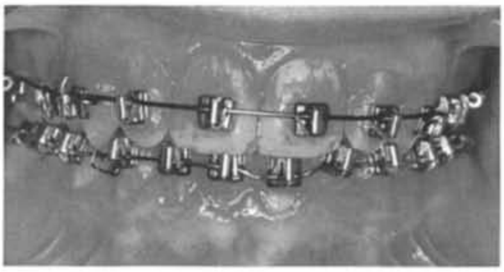
Disclosing liquid: Have the patient place a drop or two on the tongue and work the liquid through the mouth. Swish around for 30 seconds and then rinse out with water.

At this point the patient should look in the mouth and check with a mouth mirror to see if there are areas with plaque build-up. Those areas with plaque will appear red or yellow depending which type of disclosing method used (Fig. 3A & B).

Fig. 2. Disclosing tablets, solutions and mouth mirror.



A



B

Fig. 3. A - Before using disclosing solution.
B - After using disclosing solution.

MANUAL TOOTHBRUSHES

There are many varieties of toothbrushes in the marketplace. A simple method of assessing a good toothbrush is that it has a small head with soft, round bristles. Toothbrushes vary in size and shape of handle and the size and arrangement of bristles. (Saxer *et al.*, 1997) There are also special orthodontic toothbrushes available. The orthodontist/dental hygienist will recommend the appropriate type of toothbrush for the patient (Fig. 4).

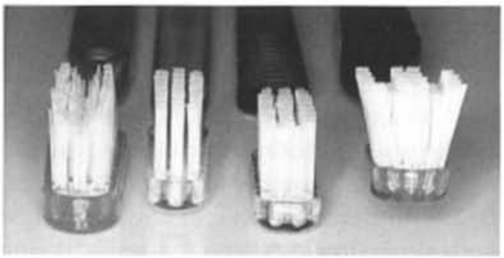


Fig. 4. Manual toothbrushes - Variety of shapes, sizes and amounts of bristles.

TOOTHBRUSHING METHOD

First, remove all elastics and other removable appliances.

Brush the buccal/facial areas of the maxillary teeth and mandibular teeth. Aim the bristles of the toothbrush toward the

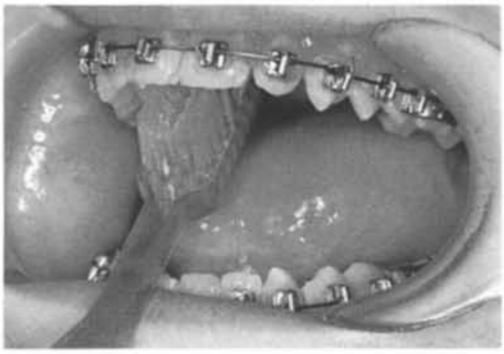
gingival tissue at a 45 degree angle to the tooth and gently rotate the toothbrush in a small circular motion while the bristles remain in the same place. Place the toothbrush in the next segment of 2 - 3 teeth and repeat this procedure. Repeat around the mouth until all gingival margins have been cleaned.

To clean the bracket areas, aim the toothbrush directly onto the brackets and with the same circular motion, brush from the bracket to the incisal/occlusal area (Fig. 5A).

Next, brush the palatal/lingual areas of the maxillary and mandibular arches. Using the same angle and brush action, clean these surfaces as on the buccal. Make sure the patient tilts the toothbrush lengthwise to reach the incisor areas (Fig. 5B). Finally, place the toothbrush on the occlusal surfaces and scrub back and forth to clean these areas.

Rinse and check to see if the brackets and teeth are clean and shiny. The patient can use a disclosing tablet or solution to check him/herself especially if they are not used to cleaning well. The use of a fluoride toothpaste is highly recommended for the prevention of dental caries.

A



B

Fig. 5. A - Toothbrush bristles aimed at 45° toward gingival margin.

B - Maxillary and mandibular incisors (lingual), the toothbrush is positioned lengthwise and moved in a circular motion.

ELECTRIC TOOTHBRUSHES (FIG. 6)

There has been a resurgence of the electric toothbrush. There are many types available through the orthodontist surgery and through chemists and department stores. Oral B (Oral B, North Sydney, Australia) has a small round head, Interplak (Regional Health Care, Roseberry, Australia), and Sonicare (Optiva Corporation, Bellevue, USA) have a more typical toothbrush head. The Rota-dent brush (Rota-dent, Kusnacht, Switzerland) is a universal pointed toothbrush which allows the patient to clean the space between the bracket and the archwire. A patient must learn to use an electric toothbrush correctly as with a manual toothbrush otherwise, he/she can still miss plaque and food debris. This type of toothbrush does not guarantee the end of decalcification, caries or gingivitis (Seintze *et.al.*, 1996).

Fig. 6. Electric toothbrush attachments - Oral B round shape and Interplak traditional toothbrush shape.

AUXILIARY PLAQUE CONTROL MEASURES

Superfloss

Superfloss (Oral B, North Sydney Australia) is a special type of floss designed to clean bridges, wide spaces and around braces. It consists of a stiff end to thread under appliances or teeth, a wool, spongy type of floss to clean around appliances and regular floss.

Method

Using the stiff end of the Superfloss, thread between the teeth and pull through until the spongy end is in contact with the teeth. Curve the Superfloss around the side of the tooth and slide under the gingiva. Using a back and forth motion, slide the Superfloss up and down on the side of the tooth. Move the floss to the adjacent tooth and repeat the process. Care must be taken by the patient so that the Superfloss is not forced under the gingival tissues.

WOODSTICKS

Woodsticks e.g., Interdens (Roche, Dee Why Australia) Oral B Dental Woodsticks (Oral B, North Sydney Australia) are triangular shaped, and can be used to clean plaque around the gingival margin. The patient softens the woodstick with saliva by placing the pointed end in the mouth. With the flat side towards the gingival, insert the woodstick between the teeth. Gently move the woodstick with an in and out motion. The patient then follows the contour of the gingival margin with the tip to remove additional plaque. Care must be taken so the patient does not puncture the gingival tissue while using.

INTERPROMIXAL BRUSH (FIG. 7)

There are many types of interdental brushes available e.g., Oral-B Interdental Kit (Oral B, Australia), Proxabrush by Butler (John O. Butler Co., Chicago USA) , and Sensodyne Pyco-Twin (Stafford-Miller Ltd, Padstow Australia). The handles are usually straight in the centre and angled on the brush ends. There are generally two choices of brush ends, spiral tapered shape or straight cylinder shape. The type of brush used depends on the amount of space available between the tooth, brackets and archwire.

To use, insert the brush end interproximally and gently glide the brush back and forth against the tooth and the gingival tissue. This can either be inserted from the gingival or incisal edges of the teeth, whichever is easier to use.

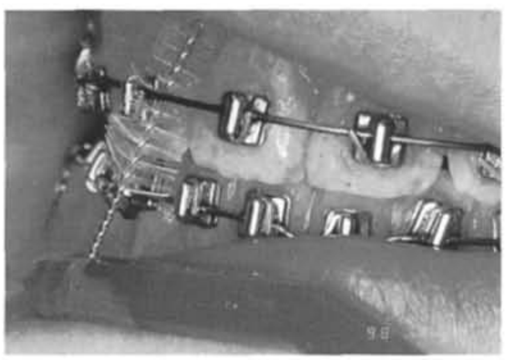


Fig. 7. Using an interproximal toothbrush. Brush is angled under archwire and gentle glided back and forth.

END TUFT TOOTHBRUSHES

These brushes can either be tapered or flat-ended brushes e.g., Oral B End-Tufted brush (Oral B, North Sydney Australia) and Sensodyne Interdental Brush (Stafford-Miller Ltd., Padstow Australia) and are ideal to massage and clean the spaces interproximally, as well as, around and under orthodontic appliances. With the tapered end tuft toothbrush, use a short in and out motion interproximally against the teeth. The flat-ended toothbrush is used in a circular motion gently at the tooth and gingival margins.

ORAL IRRIGATION DEVICES

These devices are used for flushing out food debris around orthodontic appliances. Sometimes a problem can occur with the water irrigation device if patient puts the pressure level too high. The irrigator should be aimed at a 90 degree angle to the gingiva and brackets areas and the pressure or pulse reading should be started out at a low level. Once the patient is confident in using the device, a medium setting could be used . Higher settings risk injuring the gingival tissues. (Burch, *et.al.*, 1994)

FLUORIDE RINSES AND GELS

Although fluoride is found in most water supplies, supplementary treatments are needed during orthodontic treatment because of the increased amounts of bacterial plaque and difficulty in keeping appliances clean. The use of topical fluoride gel applied directly to the teeth with a toothbrush is an effective method on a weekly basis. Fluoride forms fluorapatite which increases the strength of the enamel and, therefore, reduces solubility. Remineralisation of enamel can occur with the daily use of a fluoride gel during the early stages of decalcification around bands and brackets.

Staining can develop with the use of stannous fluoride (0.4%) but this is more likely in the presence of poor oral hygiene and can be eliminated by oral prophylaxis (Boyd and Chun, 1994).

Recommended doses for topical fluoride gel are stannous fluoride 0.4%, sodium fluoride 0.05% and acidulated phosphate fluoride (1.23%).

Recommended doses for fluoride mouth rinses are acidulated phosphate fluoride (APF) 0.02% (daily), sodium fluoride (NaF) 0.01% (daily), partly acidulated sodium fluoride 0.04% (daily) and sodium fluoride 0.2% (weekly). Fluoride mouthrinses are safe following manufacturer's directions. Rinses are not recommended for children under 4 years of age. (Cameron and Widmer 1997)

Method

Application of Fluoride gels

After thoroughly brushing and cleaning teeth, place a small strip of fluoride gel on the toothbrush. Brush in small circles until all tooth surfaces are covered. Swish in mouth for 30 seconds and spit out as much gel as possible. Do not rinse, eat or drink for 30 minutes.

Chlorhexidine and Chlorofluor

Chlorhexidine mouth rinses and gels (0.2% chlorhexidine gluconate) can be beneficial for patients with gingival problems. Reduction of plaque retention and reduction in bleeding with the use of Chlorhexidine rinses have resulted in less inflammation and decreased probing depths. Chlorhexidine is used to reduce the discomfort of mouth ulcers and can help control plaque on removable appliances. Gingival hyperplasia caused by *candida* (thrush) is often seen in the palatal areas under retainers when appliances have not been cleaned or brushed properly. (Anderson *et.al.*, 1997)

Chlorofluor (PDS, Yarra Glen Australia) is a combination of chlorhexidine gluconate (0.2%) and sodium fluoride (0.003%) mouth rinse/gel. This has an advantage in that the patient can control caries and control of plaque and gingivitis.

CARE OF REMOVABLE APPLIANCES

Appliances can be worn full-time (including eating) or part-time (few hours per day). The patient needs to be made aware of the importance of keeping the appliances as clean as possible in order to reduce bacteria and food debris from close contact with gingival tissue and teeth and thus reducing gingival hyperplasia, thrush, decalcification and caries (Fig. 8).

Appliances should be cleaned thoroughly after eating and before retiring at night. Care should be taken as not to drop the appliance while cleaning. Filling the sink partly with water can eliminate the possibility of the appliance breaking. The use of soapy water and a toothbrush is a quick easy method of cleaning the appliance. Bleach and antiseptic solutions should be avoided as these craze the acrylic of the removable appliance.

Soaking the appliance in Steradent (Reckitt & Colman, West Ryde Australia) or Polident (Stafford-Miller Ltd., Padstow Australia) solutions once a week for 15 minutes can keep down the amount of build up of plaque and calculus. If there is much calculus build-up, then the patient should have the appliance professionally cleaned by the orthodontist in an ultrasonic cleaner.

Whenever the appliance is taken out of the mouth, it should be placed in the plastic storage case given to the patient by the orthodontist. This will prevent the loss of the appliance by being thrown away, stepped on or chewed on by pets.

Fig. 8. Gingival inflammation due to poor oral hygiene and lack of cleaning of a removable appliance

PRE CARE-ORTHOGNATHIC SURGERY

Before orthognathic surgery, the upmost care should be given to gingival and tooth tissue. To be assured that these tissues are at their healthiest, a full mouth periodontal and caries charting, as well as, corrective treatment are in order. A thorough scale and oral prophylaxis are needed to keep the bacterial levels down while being wired after surgery. Hospital nursing staff which will take care of the patient in hospital, as well as, family members need to be aware of the patient's special oral hygiene needs during the post-operative period.

POST SURGERY DIET

Orthognathic surgery seriously limits the types of food one can chew or swallow. There is also a possibility of reduced appetite and apprehension of injuring the surgery site. It is important that the patient keep up their normal weight and that the foods eaten give him/her the nutritional requirements to help their body repair itself quickly. Daily intakes of cereals, rice, pastas, fruits and juices, vegetables, meat, fish and poultry, and milk products are necessary to keep up those nutritional requirements.

Foods must be either pureed or liquefied with a blender or food processor. A wide variety of foods can successfully be processed in this manner and a variety of flavours, colours and temperatures may make this more appealing.

In addition, dietary nutritional supplemental drinks are available from the chemist. These drinks contain recommended dietary allowances for vitamins, proteins, carbohydrates, fats, and fibre.

POST CARE-ORTHOGNATHIC SURGERY

During the first 24 hours, the patient is encouraged to use normal saline rinses. After this, use of Chlorhexidine rinses daily and irrigation with a 20 ml syringe and 18 gauge blunt needle two to three times a day is necessary. If the patient can tolerate toothbrushing after a few days, a very soft toothbrush, an end tuft toothbrush or an electric toothbrush can be used 3 - 4 times daily gently around the gingival tissues. The patient needs to visit the dental surgery once a week for a short appointment for an oral prophylaxis and an oral hygiene review. This could be for the six to eight weeks that the patient is incapable of cleaning. Smoking is a definite no as this retards the of healing of the soft tissues.

DIET FOR FIXED ORTHODONTIC APPLIANCES

Attention and care need to be taken by the patient when eating. Hard, sticky foods should be totally avoided. These foods lead to breakages of brackets and bending of archwires and, therefore, delaying treatment. A list of these foods should be placed where the patient is likely to see it e.g., refrigerator door.

FOODS TO AVOID

Ice, chewing gum, pretzels, Doritos and CC's, potato crisps, nuts, popcorn, caramels, gummy type lollies, muesli bars, bagels, thin and crispy pizza crust, taco shells. Raw fruits and vegetables, as well as, crusty bread should be cut or broken in small pieces and chewed on the molars.

Pens, pencils and fingernails do not belong in the mouth and do not need to be chewed.

Fixed appliances are designed to be removed with relative ease once treatment is complete. Cementation of the attachments *will resist normal eating patterns* and a healthy diet. Breakages are generally as a result of accidents or lack of care.

A good rule of thumb — if in doubt on whether it will have an adverse effect, don't eat it or call the orthodontist.

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Orthodontics and Dentofacial Orthopaedics

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Orthodontics and Dentofacial Orthopaedics offers a fully referenced, in depth and up to date coverage of the theory and practice of this discipline from the younger patient to the adult. Each chapter has been written by experienced academics and clinicians and enhanced with many photographs and line drawings to provide a highly readable and informative book.

There is a strong core of commonsense diagnostic principles and practical advice which will serve as a valuable reference for all with an interest in dentofacial variation.